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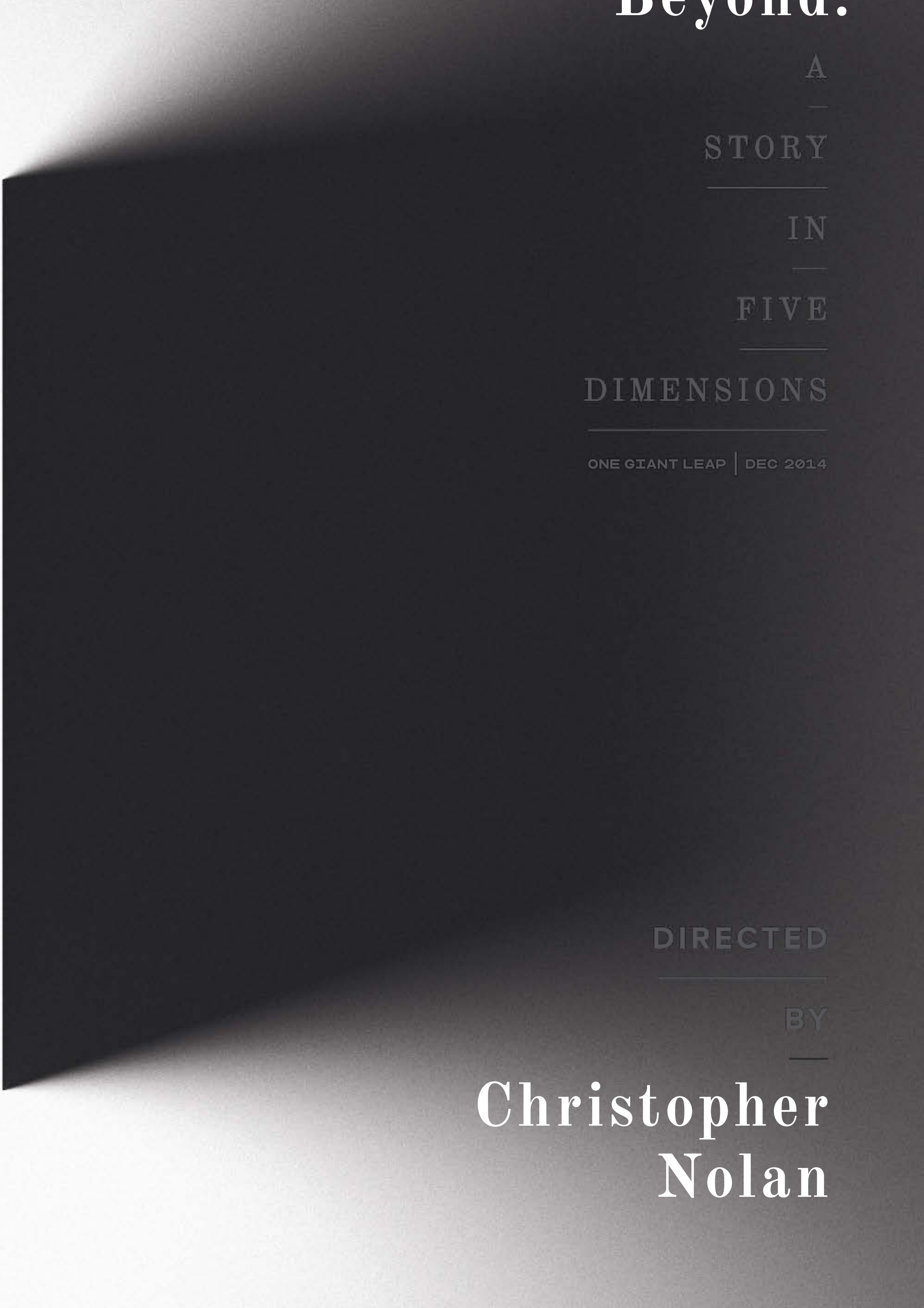

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“THE ONLY THING WE CAN BE SURE OF ABOUT THE FUTURE IS THAT IT WILL BE ABSOLUTELY FANTASTIC.”
– ARTHUR C. CLARKE, 1964

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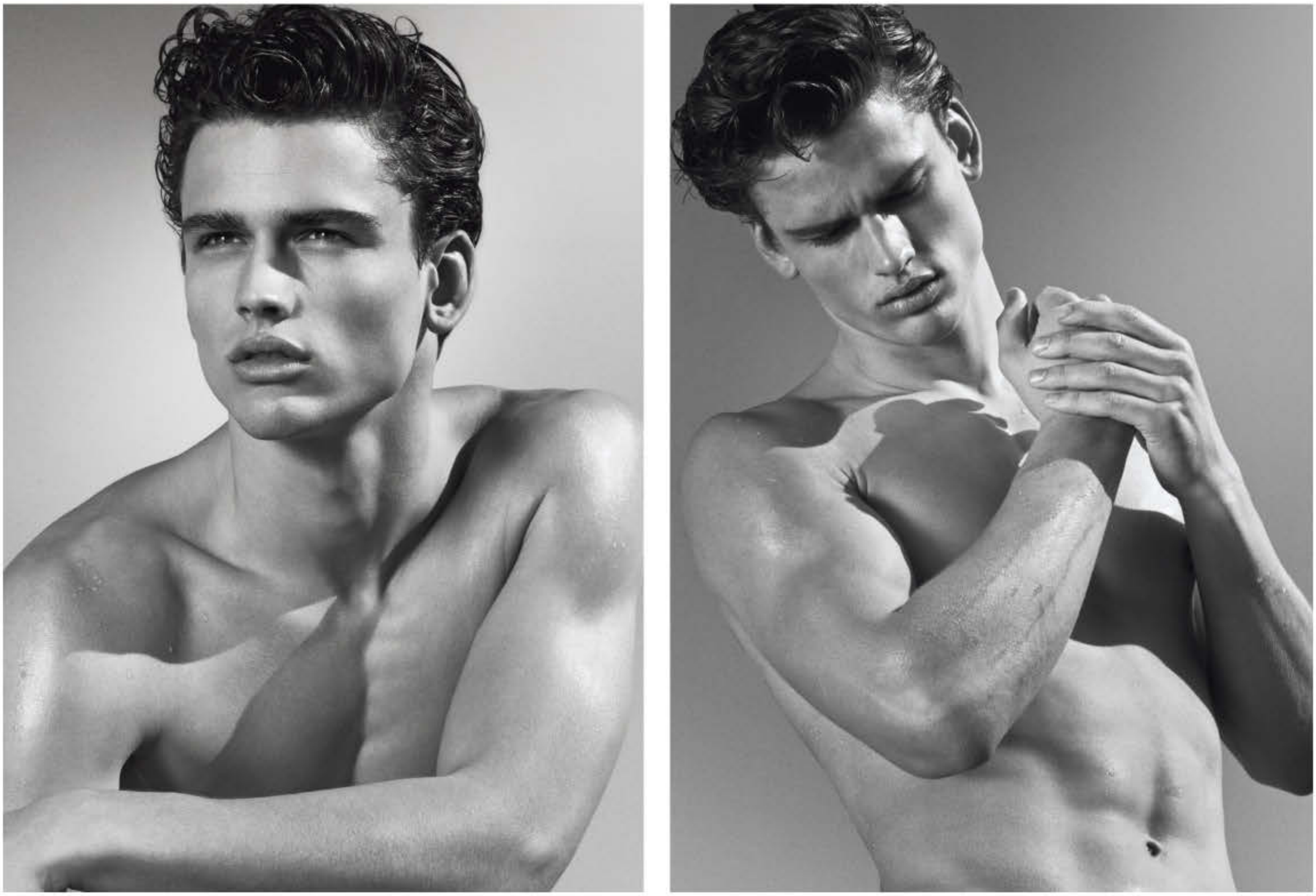

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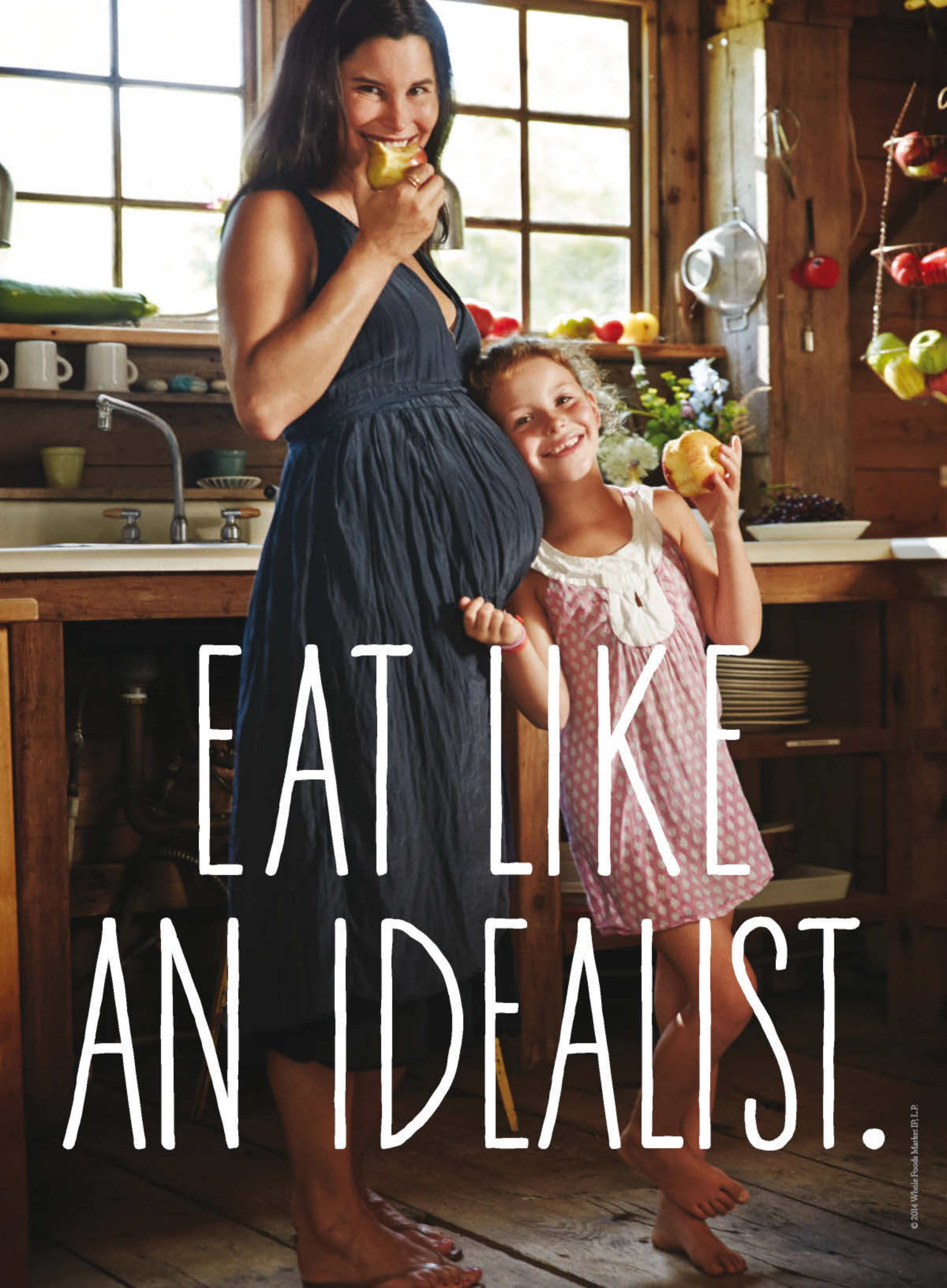

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PLEASE RECYCLE THIS MAGAZINE

PAY ONLY THE 1923 PRICE FOR THINGS, SUCH AS HOUSES. THEN BUY GOOGLE WITH THE PROFITS.

JAM WITH JIMI.

COMPLETE ALL TASKS, THEN SURPRISE MYSELF WITH BONUS GOLDEN HOURS.

BITCOIN.

BACKPACK THROUGH HUMAN HISTORY, STOPPING EVERY 100 YEARS TO CHAT WITH LOCALS.

MAKE AN APP TO REPLAY CERTAIN LIFE MOMENTS WITH MOVIELIKE SOUNDTRACKS.

PLAY "JOHNNY B. GOODE" AT MY PARENTS' HIGH SCHOOL PROM.

TRAVEL BACK TO WATCH PINK FLOYD RECORD "TIME" AT ABBEY ROAD STUDIOS.

GO BACK TO THE ERAS OF MY FAVORITE MOVIES AND POP SONGS AND EXPERIENCE THEIR CULTURAL IMPACTS IN FULL CONTEXT.

FREEZE EACH BASEBALL PITCH, THEN HIT THE BALL AND START TIME AGAIN, GIVING THE ILLUSION THAT I'M TED WILLIAMS AND HANK AARON ROLLED INTO ONE.

NEVER WAIT FOR (OR MISS) A BART TRAIN AGAIN.

GIVE THE BEST CHRISTMAS PRESENT: MORE TIME.

JUMP FORWARD TO WHEN READERS CAN ACTUALLY HOLD THIS ISSUE. OH WAIT! I DID IT!

MAKE THOSE LOW-HUMIDITY, 70-DEGREE SAN FRANCISCO FALL DAYS LAST FOREVER.

SEE WHAT THINGS WERE LIKE PRE-BIG BANG—AND GET THE HELL OUT BEFORE IT HAPPENED.

VISIT EONS WELL BEYOND MY LIFETIME.

DILATE IT BEFORE MY WRITING DEADLINES BY THINKING HEAVY THOUGHTS.

SLOW IT DOWN 4 PERCENT.

GO INTO THE FUTURE TO SEE HOW MY DECISIONS PLAY OUT. I CAN ALREDY TELL THIS WILL END BADLY.

MAKE MY DAY LONGER THAN EVERYONE ELSE'S TO GET MORE DONE. MYTIME = 4 • OTHERPEOPLESTIME

MARRY LAURA ALL OVER AGAIN.

SING ABOUT IT LIKE CHER. (RIM SHOT!)

WATCH THE MOMENT WHEN THE UNIVERSE BEGAN.

TELL COLLEGE MAX THAT ENGLISH IS A BAD CHOICE OF MAJOR.

THE WORKDAY
CAN SURVIVE AT ANY ALTITUDE.

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KEEP CLIMBING
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POLAR ICE PACK
SUBMERGED POLAR TRANSIT
NAUTILUS 1958
1958
THEY SAILED BENEATH THE NORTH POLE.
THEIR WATCH HAS SAILED ACROSS TIME.
JAEGER-LECOULTRE
GEOPHYSIC
SWISS MADE

JAEGER-LECOULTRE

THE FIRST CROSSING UNDER THE NORTH POLE

On August 3rd 1958, the United States Admiralty received the following message: "Nautilus 90° North". The *Nautilus* submarine and its crew had achieved the feat of crossing the North Pole by sailing under the ice floe. This unprecedented challenge was taken up within the context of the International Geophysical Year (IGY), during which the global scientific community united in a common purpose: the advancement of research and of universal scientific knowledge.

THE GEOPHYSIC®, A WATCH TO MATCH THE ACHIEVEMENT

As a reward, Captain Anderson received a watch worthy of such an impressive accomplishment: the Geophysic® Chronometer by Jaeger-LeCoultre, a paragon of reliability and precision that has now become a legend. Its innovative mechanism along with its resistance to magnetic fields, made it the natural choice to award such an accomplishment. Through the new Geophysic® 1958 watch, Jaeger-LeCoultre pays tribute to the inventive spirit that defined the year of 1958.

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GO BACK IN TIME TO THINK OF A BETTER RESPONSE TO THIS.

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ZOOM AHEAD TO SEE WHAT FURTHER AMAZING ADVANCES ARE IN STORE FOR HUMANITY. HOW WE EVOLVE, AND ULTIMATELY HOW IT ALL ENDS … IF INDEED IT DOES.

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SLOW DOWN THE GOOD MOMENTS. SPEED UP THE BAD ONES. AND REWIND AND REPLAY THE EXTRA-GOOD PARTS! CAN I JUST GET A REMOTE FOR TIME?

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PAUSE IT AND MAKE A SERIOUS DENT INTO THE EVER-GROWING STACK OF UNREAD BOOKS ON MY SHELF.

SKIP WINTER AND NEVER SLIP ON ICY SIDEWALKS AGAIN.

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In independent floorcare tests, the new DC59 Motorhead vacuum out-cleans the top five best-selling full-size vacuums across carpets and hard floors. Without the hassle of a cord.*

dyson

DC59 motorhead

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*Tested against upright market, dust loaded, using ASTM F608, ASTM F2607, IEC 60312-1 5.2, 5.9. Using competitor NPD sales volume data, MAT June 2014.

SOCIAL

Interactive Action

Want the inside scoop—the stories behind the stories in this issue? Photographer Uta Kögelsberger (above), game designer Marc ten Bosch, editors Robert Capps and Adam Rogers, and others will be hanging out in the comments sections of WIRED.com—just chilling, no big deal, answering your questions. Watch WIRED.com and our Twitter and Facebook feeds for the schedule.

VIDEO

Gigs … in … Space!

Living and working in space is romantic, heroic, and dangerous. It's also prosaic, uncomfortable, and a little bit gross; even everyday things like, oh, say, drinking a glass of water can get complicated, as astronaut Reid Wiseman (@astro_reid) shows. Let's just say the glass only gets in the way. See the video in our tablet edition and on WIRED.com.

DIGITAL

Flight Record

That X-1A that Sam Shepard (playing Chuck Yeager) flew in the 1983 space epic *The Right Stuff* was just a model. A 4½-foot-long, $6,000 model that visual effects supervisor Gary Gutierrez threw out a window while the crew held its collective breath and prayed for a perfect shot. "The next day we showed [director] Philip Kaufman the footage," Gutierrez says, "and he loved it." He tells the nerve-racking tale in an oral history of *The Right Stuff*, alongside Yeager himself, author Tom Wolfe, stars Shepard, Ed Harris, Jeff Goldblum, Harry Shearer, and many others. Read the extended cut on the web and in the tablet edition of WIRED.

The Gadget Lab Gift Guide

It's better to give than to receive. It's also harder. But not to worry! Gadget Lab has your back. Check out WIRED.com for more than a dozen personality guides that cover every lucky duck on your list, from the neat-freak to the action hero. We even have a killer selection of last-minute ideas, just in case Santa (that means you) has to make an unexpected party stop.

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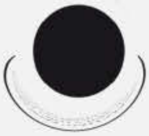

Black Magic

Check out the black hole that opens this issue's Q&A with Kip Thorne and Chris Nolan. It's warping the article! And it's made with science—specifically, research that astrophysicist Kip Thorne did for *Interstellar*, which Eugénie von Tunzelmann at VFX house Double Negative spun up again for our black hole and the wormholes that connect the two parts of the Q&A. Where does that black hole lead? Through spacetime back to a November article on the rendering process. Read it at: wrd.cm/1CVF2ms

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INCEPTION

WHAT IT'S LIKE TO COLLABORATE WITH CHRISTOPHER NOLAN.

BY SCOTT DADICH

EDITOR IN CHIEF

Dadich, Nolan, and Emma Thomas at the *Interstellar* premiere.

ALEX J. BERLINER/ABIMAGES FOR PARAMOUNT PICTURES

IT SHOULD COME as no surprise that the WIRED office is full of rabid Christopher Nolan fans. Over the years, we've hosted viewing parties for *Dark Knight* trailers, run an entire magazine section dissecting the timelines and influences of *Inception*, and maniacally discussed just about every shot and line from the man's oeuvre. So last year, upon hearing that Nolan was taking on *Interstellar* as his first post–*Dark Knight* directing effort, we were ecstatic. The staff immediately started fantasizing about what we might do. A McConaughey-Hathaway-Chastain cover! An essay about the new, Nolan-inspired golden age of sci-fi! A behind-the-scenes look at the film's creation! Alas, as is so often the case with magazine-making, the real world conspired to foil many of our plans. We assigned a short feature about one of Nolan's collaborators and left it at that. ¶ But late this summer, a single yellow Post-it note waiting on my desk rekindled our hopes. The message was simple but full of promise: "Chris Nolan called." Below those three words was a number. I picked up the phone and learned, to my amazement and delight, that Nolan is as much a fan of WIRED as WIRED is of him. By the next morning, we had agreed on a path: The December issue would be his to guest-edit. Days later, a team from WIRED was sitting in the Syncopy production facilities, waist-deep in ideas and notes, scribbles for the stories that now fill these pages. That would be the first of many work sessions, brainstorms, and story reviews for our very own Christopher Nolan project.

For me, this was a fantasy come to life. In the summer of 2001, I went to a tiny indie cinema in downtown Austin to check out *Memento*. I was astonished by what I saw on the screen—a film that didn't just entertain me but twisted my brain. In the decade-plus since, Nolan has proven himself a singular voice in filmmaking, a soulful and imaginative artist who layers labyrinthine story structures between head-exploding plot twists and spectacular visuals. The things that so affected me in *Memento*—the shifting perspectives, the cerebral ambition—have grown to become signature elements of his work. Nolan respects his audience. He doesn't spell out his ideas; he makes us think, concentrate—maybe even watch the film repeatedly—to discover what he's up to. He combines intellectual rigor with a sense of drama, adventure, and pure pop pleasure. Nolan and his collaborators, both his wife and producer, Emma Thomas, and brother, Jonathan, have managed to merge science and storytelling in ways that defy expectation and fire our imaginations.

For those of us at WIRED, making this issue has felt like the collaboration of a lifetime, a chance to play in a universe-sized sandbox. The stories inside come from Chris and Emma and their world. They impressed us in so many ways these past few months, and not the least with their generosity, both in time and spirit. We've come to understand their creative process, their appetite for discovery and for invention, and perhaps most important, their endless ambition. I'll refrain from spoiling the fun, but I will tell you this: Like all Christopher Nolan projects, this one will reward scrutiny and attention to detail. We hope you enjoy it.

Scott

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SPACE, TIME, AND MULTIPLE DIMENSIONS

GUEST-EDITED BY

CHRISTOPHER NOLAN

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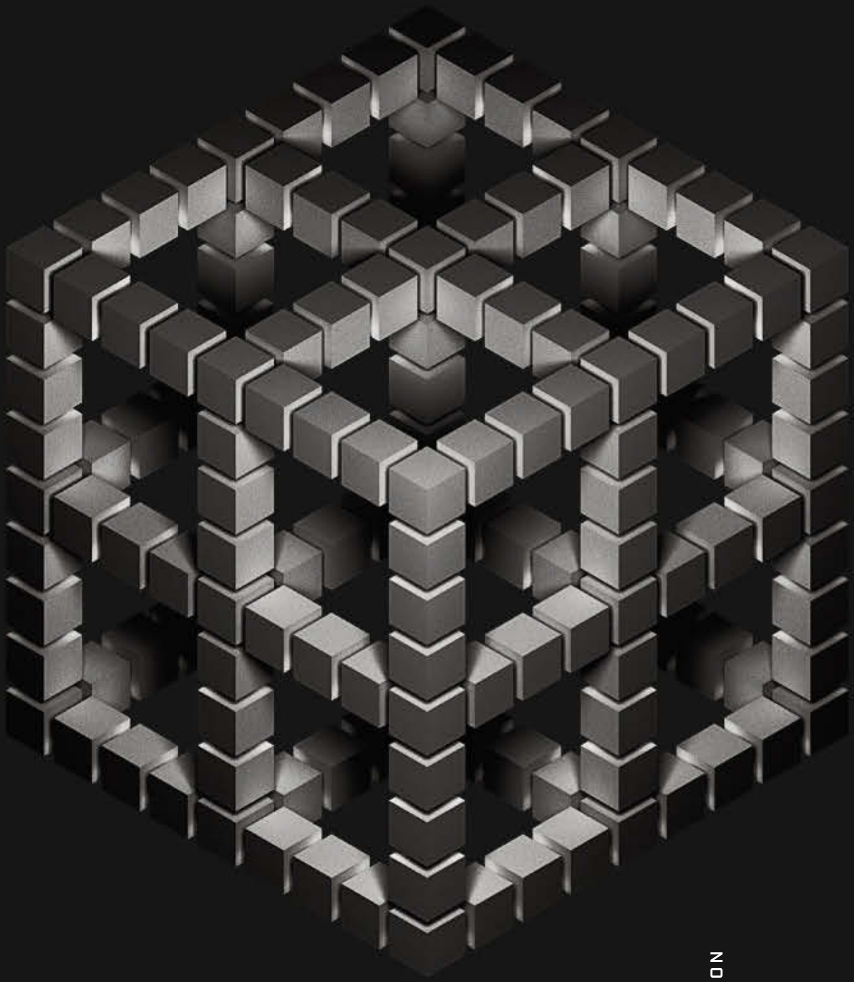

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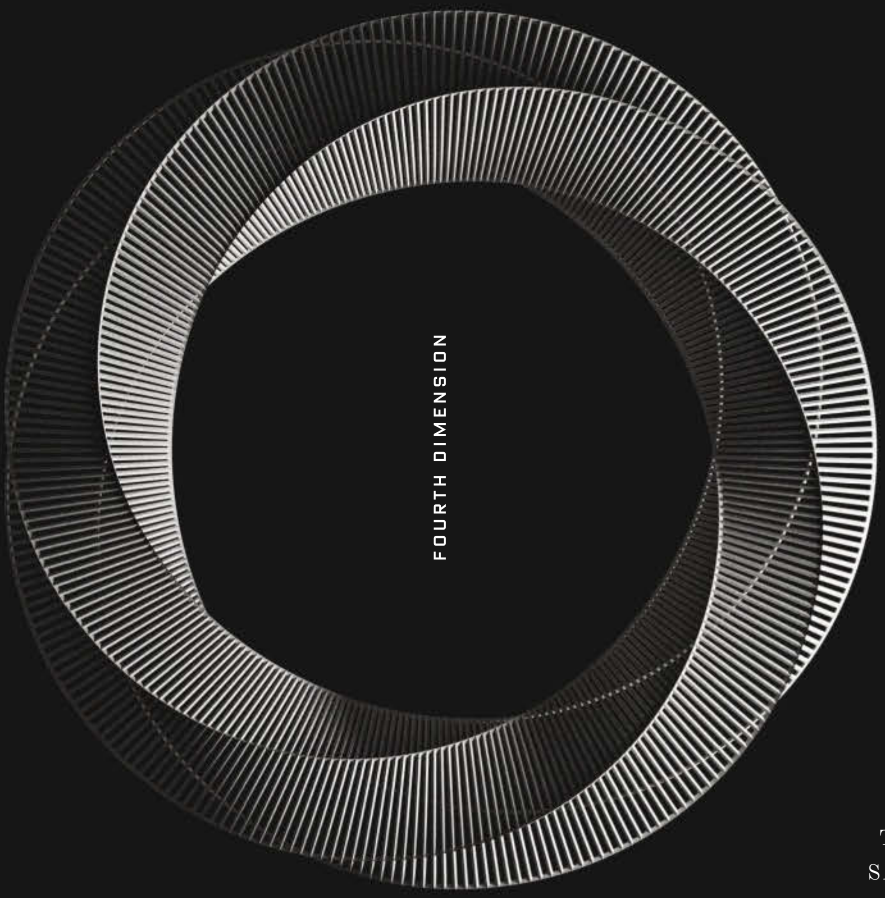

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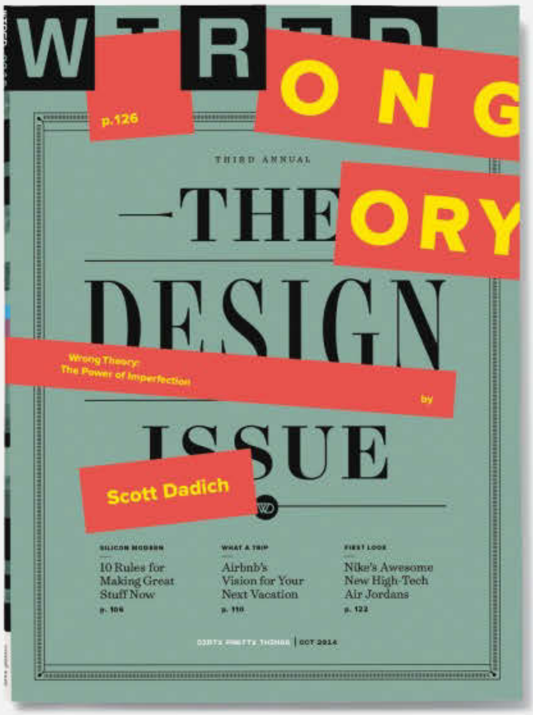
BE WRONG

Tiny type. Gray text on black backgrounds. Neon colors behind overlapping blocks of copy. Oh, we see your letters. Kvetch all you want—but we kinda like the magazine this way. The boss sure does; in WIRED's third annual Design Issue in October, our editor in chief, Scott Dadich, laid out the thesis behind what he calls Wrong Theory. Break the rules—like the one that says every graphical element should serve a recognizable function—and readers will be jolted to attention. It's also true outside the pages of a magazine, which, says Dadich, means it's time for technologists to shake things up a little too. So go ahead, tell us that the text on page 114 is indecipherable. But just know that it's all part of the plan.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RE: "DESIGN WRONG"

"GREAT ARTICLE. I WONDER IF WRONG THEORY COULD HAVE AN APPLICATION IN SCIENCE TOO."

Álvaro Ribas Gómez (@AstroRibas) on Twitter

"It's almost weird to read this article and not see graphic designer David Carson mentioned in it, either for or against. The Ridley Scott layout could have been pulled from the pages of *Ray Gun* magazine. It's a nice article, but this has been going on since well before 2006."

DocBenway on WIRED.com

(Scott Dadich responds: "I greatly admire Carson's work, but I don't really classify him as Wrong Theory. He's more like punk— intentionally subversive from the start.")

"As someone who studies what makes people creative, it felt refreshing to get a new insight myself—that little smile you get when you learn something new."

nickskillicorn on WIRED.com

"Your article is all about design using imperfection. Well, I think WIRED is excelling there. I read WIRED for the content and disagree with making it deliberately harder to read."

Steve via email

RE: "I WANT CANDY": TRICKS FOR MAXIMIZING YOUR HALLOWEEN CANDY TAKE

"My 8-year-old took issue with your suggestion to 'target the perennially festive' on Halloween. She said, 'No, if you go on streets with all the decorations, they know a million kids are coming and they get cheap candy. You'll have to wait in line for, like, a jawbreaker. Go one block over for no lines and big Snickers!'"

Jennifer Erickson via email

RE: "NO LIMIT": TWO GAMBLERS HACK VIDEO POKER—AND PAY

"It makes you wonder how many folks out there have discovered such things but did not get themselves caught and are currently traveling the world on a handsome salary."

flat5 on Reddit

RE: VIDEOGAMES MAKE KIDS SMARTER

"I'm in an engineering program, and *Minecraft* and Legos are the prime reasons I got into it."

Ricky Knoxville on Facebook

RE: "FEAR AND LIKING ON FACEBOOK": THUMBS UP FOR EVERYTHING

"I'd love (like?) to see a coordinated international 'Like Everything' day, just to mess with Facebook, in the spirit of Andy Warhol."

robogobo on WIRED.com

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FIRST DIMENSION: LINE

A ROW OF BOOKS, A ROBOT'S LIMBS, IMAGES ON A FILMSTRIP—THE ORIGINS OF THE STORY.

"MANKIND
WAS BORN ON
EARTH. IT

TIME. SPACE. DIMENSION.

LET'S LEAP BEYOND THE LIMITS OF OUR WORLD.

BY

CHRISTOPHER NOLAN

GUEST EDITOR

DAN WINTERS

SPACETIME. One of the most stimulating and challenging compound nouns. Thoughts of Einstein, of relativity, of complex physical laws that hover tantalizingly beyond our ability to grasp (I'm not writing this for Kip Thorne and his colleagues). The word pulls time down from its perch of abstraction and drags it into the mud with the other three dimensions, the ones we can get our hands into and our heads around. By doing this, however, it also suggests the limits of our world. Higher dimensions may exist, but we have no words to describe them. Mathematics can give us a glimpse, but only those of us with highly developed algebraic skills (not me, for the record). Which brings us to the most frustrating part: We can only really see the dimensions below the one we exist in—a problem never more clearly or cleverly explored than in Reverend Edwin A. Abbott's novella, *Flatland*, where a three-dimensional creature struggles to explain his existence to a two-dimensional creature who can himself see only one of the dimensions he lives in.

Film's relationship with dimensionality has always fascinated me: two-dimensional representations of three dimensions printed onto a strip whose length adds the dimension of time. Time is strikingly represented by the rapidly unspooling rolls of celluloid on a projector. If you've ever been in the booth when the film spills off the reel and onto the floor while the movie is running, you have a very tactile idea of the relentless and frightening passage of time by which we all live.

A magazine offers a far more comfortable relationship with time—we can flick through it, stop, flip back, keep it forever. It can do a good job of representing spatial dimensions through photography and design, but ultimately it's the reader's mind that defines the dimensionality of the magazine. Years ago, discussing *Memento* with a journalist, I revealed that as a left-hander I tend to leaf through magazines back to front, and we agreed this might go some way toward explaining *Memento*'s backward structure. I resisted the urge to try to give you my experience of magazines by reversing the entire issue, opting instead to encourage the WIRED staff in their fool's errand of attempting to represent five dimensions in the very substance of the magazine. Why five? Because if we can get our heads around the idea that time is just a fourth dimension, no more noble or abstract than the other three, then the fifth dimension reveals itself as the perch we have to climb onto to be able to actually view the four dimensions we know. A massive leap, but a leap we can almost conceive of.

Edwin A. Abbott's 1884 landmark suggests how we might experience dimensions beyond the ones we can perceive.

It *feels* like it should be possible, which lets us imagine a complete understanding of our four-dimensional existence rendered instantly by our new, higher-dimensional perspective. Many of the people and ideas springing from these pages push so hard in this direction (a direction we know exists but cannot visualize) that the limits of our world start to seem a tiny bit more porous than they did.

Christopher Nolan

CHRISTOPHER NOLAN

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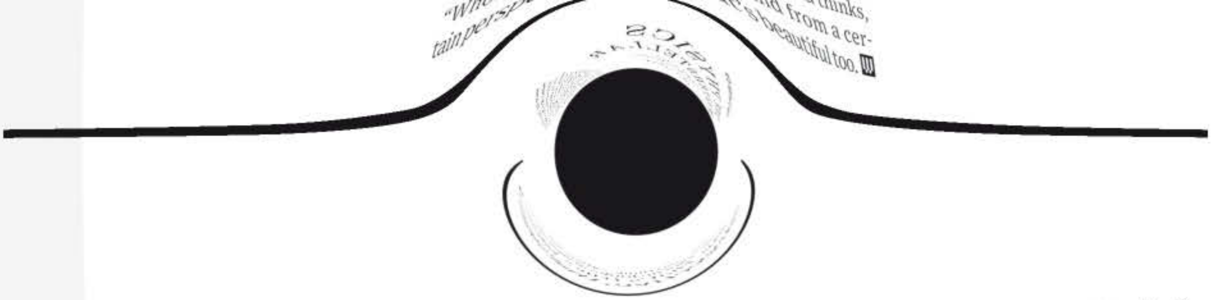

FIRST DIMENSION

THE PHYSICS OF *INTERSTELLAR*

A CONVERSATION WITH CHRISTOPHER NOLAN AND KIP THORNE.

BY ADAM ROGERS

BY THE TIME Christopher Nolan signed up to direct *Interstellar* and started rewriting its script, astrophysicist Kip Thorne had been working with Nolan’s brother, Jonathan (who goes by Jonah), on getting his ideas onto film for years. When Chris and Thorne met, they quickly found common ground: Thorne wanted science in the story, and Nolan wanted the story to emerge from science. So in *Interstellar*, time dilation—the passing of time at different rates for different observers—became an emotional obstacle between a father and his daughter. Quantum gravity, the reconciliation of relativity and quantum mechanics, became the plot’s central mystery. The visual effects team even collaborated with Thorne to make sure their depictions of a black hole were accurate as well as elegant. ¶ But to make it all work, Nolan, who never really understood algebra, had to internalize the science to which Thorne has dedicated his life. That the two men ended up liking each other was just a bonus. Here, Nolan and Thorne describe their work together, what they think they’ve achieved, and how they found détente when the story sought to break the rules of physics.

When it comes to moving through time, Thorne says, “Chris came up with his own set of rules that fit into what we physicists think we know.”

WIRED: *How’d you guys get together?*

THORNE: When Chris signed on to direct and rewrite the screenplay, he called me and said he wanted to talk.

NOLAN: I was really hoping to just get broad-strokes sign-off on some things I wanted to do with time and gravity. My brother Jonah had worked on the screenplay for years before I came on the project and had a lot of meetings with Kip. So I called Jonah and said, “So what’s up with Kip Thorne? Is he going to tell me what I can’t do?” And Jonah told me, “No, it’s really productive.” And it was true.

THORNE: I had worked closely with Jonah for several years, and I knew Chris’ work. I particularly enjoyed *Memento*, and *Inception* came out while I was working with Jonah. I loved it.

WIRED: Chris, *Inception* works without “real” science. Why did you need physics for *Interstellar*?

NOLAN: Well, it will sound strange, but to me *Inception* had a lot of science in it: A rigid set of rules, mathematical and geometrical in their nature, define that script. That took a very long time to work out. They’re not real science, but they have that quality. You always have to cheat in cinematic narrative, but you try to do it as little as possible and in a way that doesn’t violate the pact with the audience. In *Inception,* the geometry’s pretty solid.

WIRED: But without giving away too much, key *Interstellar* plot points—the main quest and the climactic scene—rely on hardcore science.

THORNE: In our first conversation, we discussed moving forward and backward in time and the fact that physicists don’t yet know for sure what the laws of physics allow and forbid. So Chris came up with his own rule set, and I came up with a way to fit it into what we physicists do think we know.

NOLAN: Yeah, that was my understanding of what you and Jonah had been pushing.

THORNE: But we had not laid out rules.

NOLAN: No, you’d been exploring and exploring it, and part of that first meeting was me letting you know there’s a new sheriff in town. Jonah loves ideas. He’s fascinated by the science. Part of my job was to find a focus.

THORNE: But you had somehow extracted a key piece of physics that is not generally

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known, the idea that gravity can reach across multiple dimensions while none of the other physical fields can.

WIRED: Wait—Kip, you've been working on gravitational waves for decades, and the Nolans just intuited them?

NOLAN: No, we didn't intuit it. What you do as a writer, working with somebody like Kip, is you—well, I'll give you a different example. In Kip's writing I found the question of whether a singularity, the heart of a black hole, is always hidden, or whether you can have what's called a naked singularity. If we knew what was going on in there we would understand a lot more about how to reconcile quantum physics with larger physics. I grabbed that like a magpie. It's one of the greatest mysteries in the universe. The gravity thing, it wasn't a question of us intuiting it. It was all the discussions that Jonah had with Kip.

WIRED: *Kip, were there places where you said, "Whoa, settle down, you can't do that. That won't work"?*

THORNE: *Only once.*

NOLAN: *Yeah, there was one.*

Continued on page 202

Continued from page 204

WIRED: Kip, did you interact with the actors, too?

THORNE: I did. A couple of weeks before he started filming in Canada, I had an email from Matthew McConaughey. He was trying to wrap his head around the role of Cooper and the science. So we met at a boutique hotel in Beverly Hills where he had holed up for the weekend to try to—

NOLAN: With all his notes!

THORNE: Right, he'd cleared all the furniture out except for a love seat and a coffee table, and he had 12- by 18-inch sheets of paper all over the floor and on the table with notes all over them, each one dealing with a particular science issue or, I suppose, character issue. He would pull up a sheet and ask questions and write notes. Then he'd pull up another one. It was a wonderful conversation. And then I had a phone conversation with Anne Hathaway for about an hour and a half. She began by saying, "I'm a bit of a physics geek."

Jessica Chastain and Kip Thorne work on making a blackboard look realistic for *Interstellar*.

NOLAN: Oh, she loves science. She was very excited to meet Kip.

THORNE: She had questions like "Are there any experimental tests for quantum gravity?" Her questions, you'd expect them from a science geek who spent the last three years reading physics. Maybe. If they were really on top of their game.

NOLAN: She loves science. Same with Michael Caine. He was super-excited to meet Kip. He took a picture with him. I've never seen Michael do that.

THORNE: The first assistant director came to me and said, "Michael Caine would like to have his photograph taken with you. Is that OK?" My jaw dropped.

NOLAN: The thing with good actors is, you don't know what they're getting from people. But there are two things going on with Kip's involvement. One is, great actors can't say lines that they don't understand. Otherwise they can't sell it. And then the other is, just by seeing somebody who has lived his life figuring these things out, they get some particular visual thing, whether it's something you do, something you wear. It's something that they absorb about what it's like to devote your life to these principles.

THORNE: That's the sense I had in my conversations with McConaughey and Hathaway. They were trying to wrap their heads around the science because they had to internalize it. With Caine it was more like he wanted to understand what it felt like to be a scientist.

NOLAN: I think one of the reasons is Michael doesn't really have any science to discuss in the film.

WIRED: Chris, did you ever think, "Holy crap, I have a plot that involves both a wormhole and a black hole, and it's really going to confuse people?"

NOLAN: No, I had a moment with Jonah's draft where I went, "Holy crap, I've got six wormholes and five black holes." I was like, guys, this is way too confusing. Kip had brilliant ideas using multiple black holes, but I just said, "No, we can do one black hole and we can do one wormhole, and that's pushing it."

THORNE: At one point in the story, a spacecraft that's going at a quarter the speed of light has to slow down. I said the only way to do it is by a slingshot around a black hole. Chris said, "No, we can't have a second black hole."

NOLAN: Can't do it.

THORNE: So I said, "OK, well, it's a bit of a cheat, but you can use a neutron star."

NOLAN: And we do.

THORNE: For me the thing I most wanted was that the film have real science embedded in it—a range of science, from well-established truths to speculative science. This is what we wound up with. And I'm just so pleased.

NOLAN: It all had to be done right for us to trust the bigger things we were doing. Early in *Interstellar* a spacecraft docks with a larger one. It was one line in the script. But it winds up being quite a lot of screen time because—well, there are two types of science fiction film. There's the type where something like this would be scary and important for people doing it for the first time, and you go through that detail. And then there's the kind of film where you go, "There's the spaceship!" And then you cut to the characters sitting in fancy chairs, they hit the button, and we're off! You have to clue the audience into which approach you're taking. Then the bigger ideas, the more adventurous scientific ideas, start to gain credibility. Your audience starts to take them a bit more seriously. ◼

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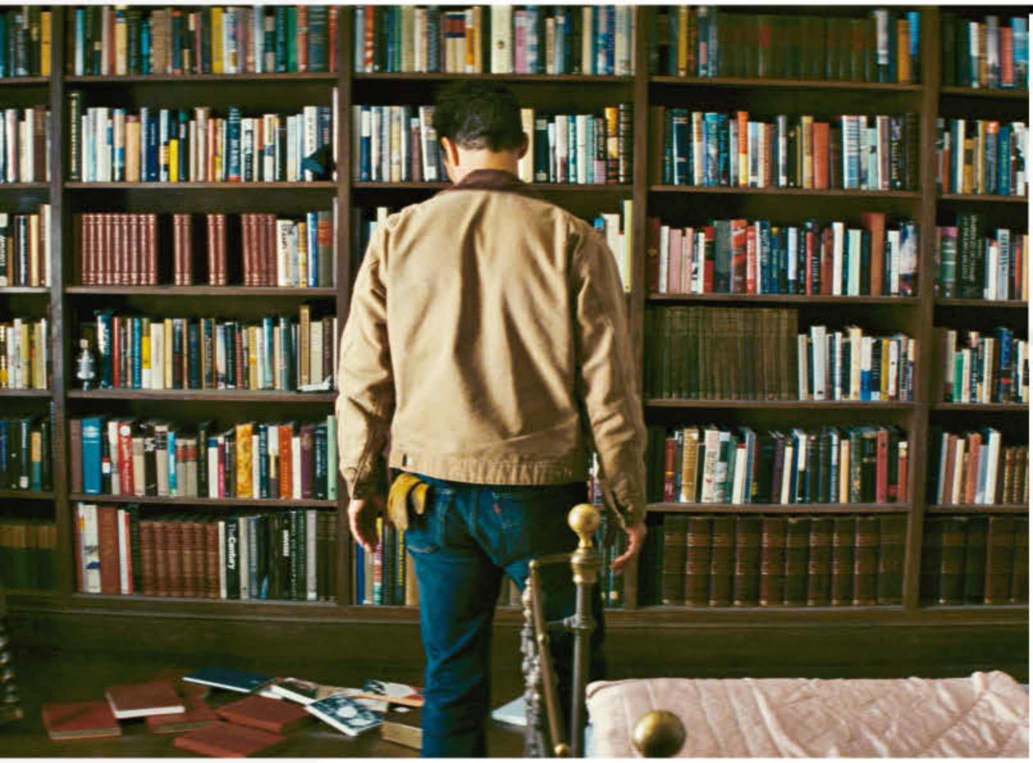


Cooper (Matthew McConaughey) in his daughter's room.

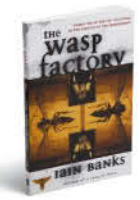
FIRST DIMENSION

SHELF PORTRAIT

KEY ELEMENTS OF A MYSTERIOUS LIBRARY.

BY JON J. EILENBERG

‘LOVE IS the one thing we're capable of perceiving that transcends dimensions of time and space," says Dr. Brand (Anne Hathaway) in *Interstellar*. But in Christopher Nolan's sci-fi epic, books can be transcendent too. Early in the film, Murph (Mackenzie Foy) attempts to decode meaning from the seemingly random volumes that fall from her bookshelves. She is certain that what she calls a ghost is using the books to try to communicate. Nolan, for his part, is absolutely using the books to communicate (Hello, *Flatland*!): The volumes he chose for her shelves relate to the characters in the film—and to his conceptual world. We asked the director about some of the featured tomes.



The Wasp Factory
Iain Banks
"Once read, never forgotten, strangely moving, horrible tale of a child and father living in near isolation."

Selected Poems
T. S. Eliot
"Concepts of time and space at their most complex are sometimes best expressed through art rather than science. Eliot's 'Four Quartets' are as thought-provoking about time as any scientific text."

The Stand
Stephen King
"A bleak scenario that hammers home the fact that our perspective on momentous events will always be intimate."

Gravity's Rainbow
Thomas Pynchon
"The most elegant title. Ever."

Emma
Jane Austen
"A beautiful name for a beautiful book (or a beautiful producer)."

A Wrinkle in Time
Madeleine L'Engle
"My introduction to the idea of higher dimensions, including the notion of a tesseract."

Labyrinths
Jorge Luis Borges
"The name says it all."

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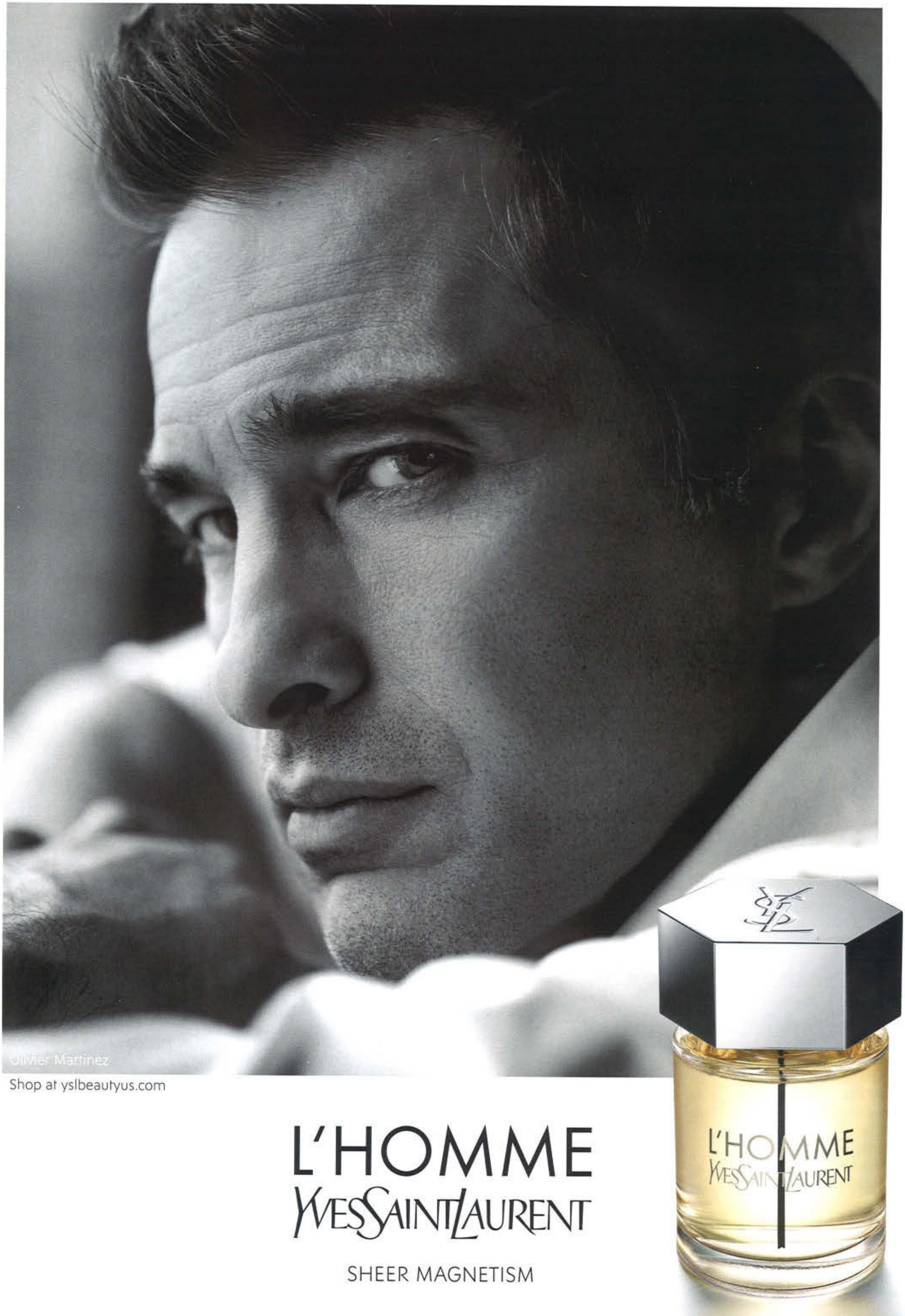

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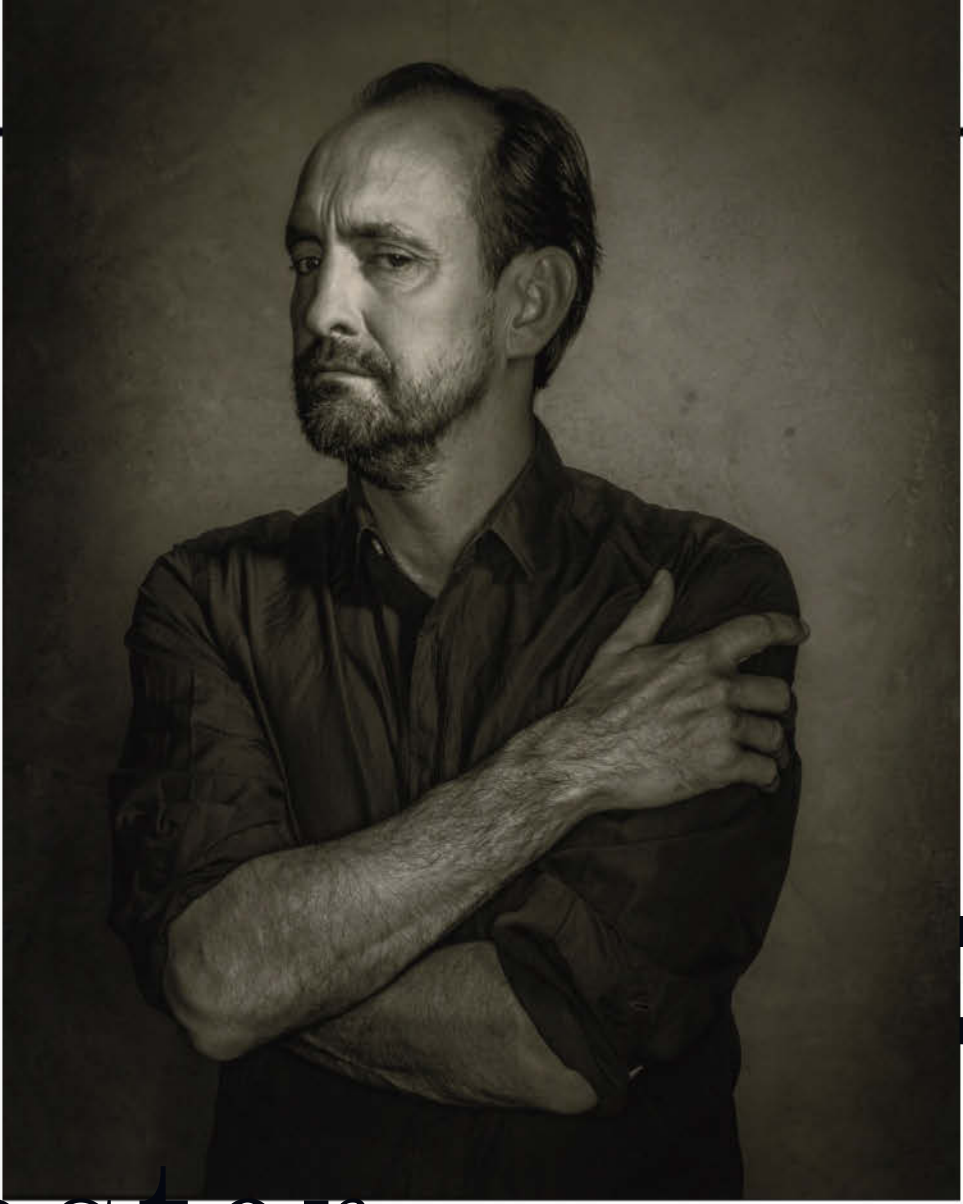


Master Builder

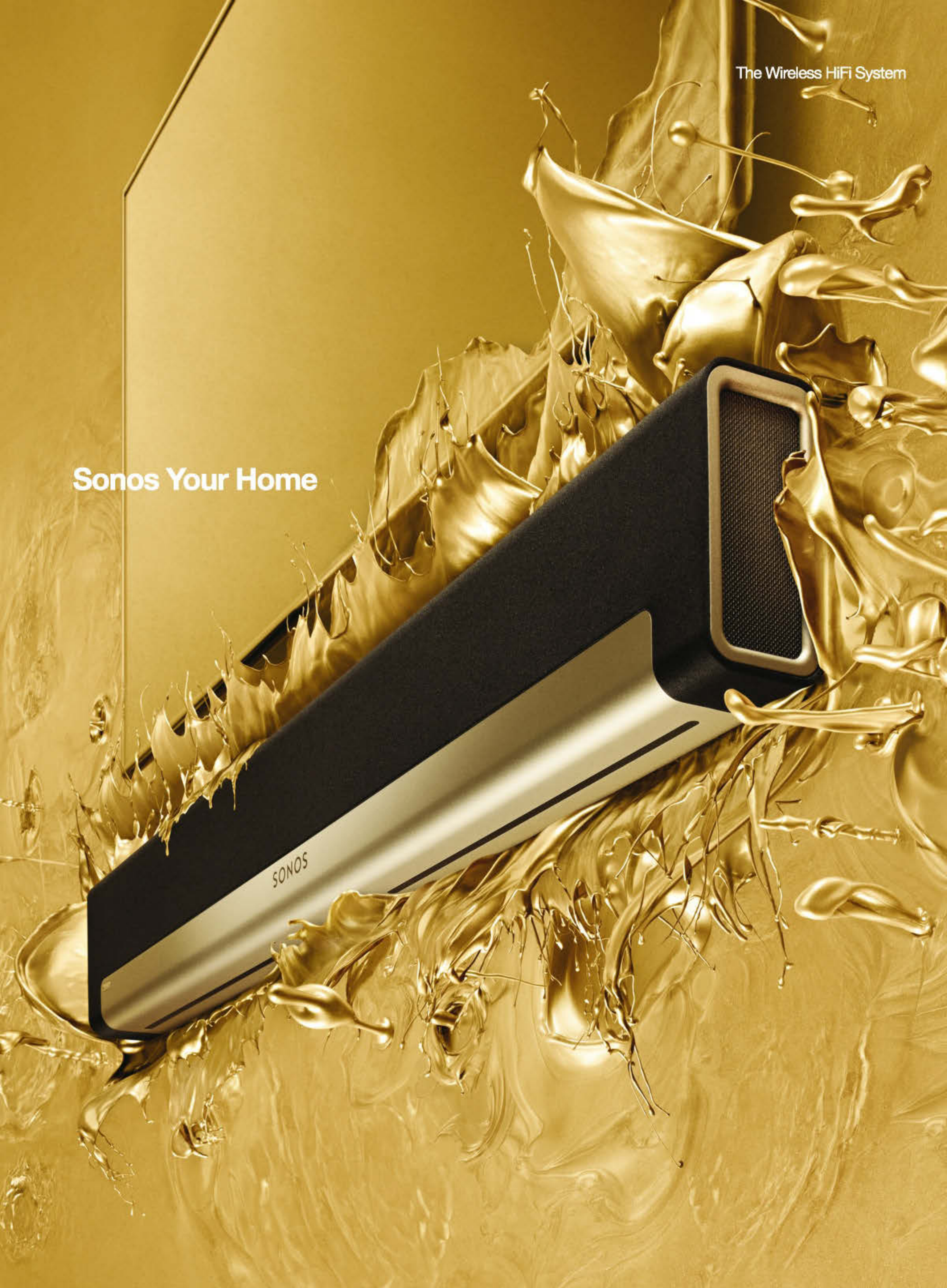
DREAMSCAPES. ICE PLANETS. BATMOBILES. UNDERGROUND PRISONS. HOW NATHAN CROWLEY TURNS CHRISTOPHER NOLAN'S VISION INTO REALITY.

BY

DANIEL ENGBER

HE DIDN'T *HAVE* TO sculpt a life-size spaceship with functional hydraulic gears. He didn't *have* to transport that spaceship to Iceland in a 747 cargo hold. But one day, during the filming of *Interstellar*, production designer Nathan Crowley found himself standing in water as far as he could see—a glacial wash only 2 feet deep. Just off camera, a giant crane was placing the 52-foot-long spaceship, its landing gear extended, into the water.

DAN WINTERS



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The Bat in *The Dark Knight Rises* (2012) was a matte-black, scene-stealing masterpiece.

“The back door opens,” Crowley says, “and the actors get out. We’re in water, in this odd landscape, the sky is heavy, and there it is—this strange world with a spaceship in it.”

Crowley is one of Hollywood’s most daring and sought-after production designers. Those in his profession are responsible for the overall look and feel of a film—helping producers and directors scout locations, designing sets and props, and determining what will be handled with effects in postproduction. Crowley is unique among his peers in that where others render, he prefers to build. His résumé includes both giant summer popcorn flicks and plucky independents; works grounded in careful historicity (the gangster biopic *Public Enemies*) and those that soar in fantasy and science fiction (*John Carter* and HBO’s upcoming *Westworld* reboot).[1] But his most celebrated work—the source of both his Oscar nominations—has been with Christopher Nolan, the director whose aesthetic most closely matches Crowley’s. Together they devised the feverish icescapes of *Insomnia*, the steampunk London of *The Prestige*, and the dark and sprawling Gotham of *The Dark Knight* trilogy. Crowley’s hallmark, building physical environments and set pieces rather than simulating them in post, is especially evident in *Interstellar*.

With his wispy hair and irregular goatee, Crowley looks like a cross between a Left Bank bohemian and a house painter: half artist, half handyman. “You don’t make the film in the art department,” he says. “You make it outside. You make it with a camera.” He learned that lesson early on, in a career that began by accident almost 25 years ago. Having grown up in North London, Crowley went to Brighton Polytechnic to study 3-D design—“a loose term for ‘I don’t know what I want to do,’ ” he says—and then decamped to Los Angeles in search of an architecture job. One night in a bar on Melrose, opposite Paramount Studios, he bumped into a guy he knew from art school. The former classmate was working on a Steven Spielberg film called *Hook*. He said they needed someone who could draw. So Crowley found himself working as a junior set designer on one of the most outlandish, overdone productions in the history of cinema. British designer Norman Garwood had been given free rein and a blank check: His soundstage Neverland, populated with live storks and flamingoes, reportedly cost $8 million on its own.[2] “*Hook* was just confusing,” Crowley says. “Garwood was building ships the size of the *HMS Victory* and flooding stages.”

Hook taught Crowley the outer limits of going big. His next job showed him an entirely different way of making movies. Garwood pulled some strings to get him on the Sony lot, where Francis Ford Coppola was making *Bram Stoker’s Dracula*. Crowley ended up on Coppola’s second unit, working mainly for the director’s son Roman. Their mandate was to spruce up the film with practical effects and vintage stagecraft trickery. That meant puppets and miniatures, double exposures, and a 19th-century theater ploy called Pepper’s Ghost, among other gambits found in dusty manuals of magic. “*Hook* taught me how to build enormous sets if needed,” he says. “*Dracula* taught me the wonders of the camera.”

Those two productions would form the axes of the Crowley method: one grand and the other

CROWLEY IS UNIQUE AMONG HIS PEERS IN THAT WHERE OTHERS RENDER, HE PREFERS TO BUILD.

[1] Nolan’s brother, Jonathan, and Crowley are working on the ’70s sci-fi western remake.

[2] *Hook* exceeded its original budget by about $22 million.

PREVIOUS: GROOMING BY LOUISE MOON; THIS PAGE AND NEXT: PHOTOS: EVERETT COLLECTION

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gritty, one expansive and the other handmade (and neither done with a computer). He has bridged the two with his devotion to found environments and a desire to extend reality rather than replace it. “He’s not excited by the size of sets,” Nolan says. “He’s much more excited by the size of things in the real world.”

Which is why, on their trip to Iceland for *Interstellar*, the duo strapped on crampons and hiked up Eyjafjallajökull, a 5,000-foot-tall volcano that last erupted in 2010.[3] The glacier is strikingly marbled with black ash, but Crowley and Nolan weren’t sure how well it would fit with the film. “We had a big debate,” Crowley says. “We’d go back and forth, stay the night, then hike back out there the next day.” Eventually they decided to use it for the movie’s frozen planet. And when local farmers directed them to that vast, shallow delta, they knew it was the perfect spot to land the spaceship on the other planet, the one covered by water. “When you see the thing that’s right, you jump on it,” Nolan says. “We’ve worked together long enough to know that immediately.”

“People have forgotten the other ways to do visual effects,” Crowley says. It may be efficient and effective to decorate a scene with digital shapes or stretch its borders with CGI. But if you build from real materials and extend from a genuine landscape, the image has a sense of weight that would otherwise be missing. It also leaves you open to the unexpected.

“Very few production designers are able to deliver scope and scale in such an unpretentious way,” says Wally Pfister, Nolan’s former director of photography. “He’s an artist who happened to fall into art direction,” says Andrew Bolton, curator of the Metropolitan Museum of Art’s Costume Institute, where Crowley has designed several fashion exhibitions over the years.

“The advantage of not faking is that you feel it,” Crowley says. You feel that realness in the eerie light bulbs of *The Prestige*, in the kludgy beauty of the Batmobile, in the tempered grandiosity of Bruce Wayne’s bunker, and in the surreal and stretched-out spacetime of *Interstellar*. Nathan Crowley doesn’t have to build his worlds by hand, but he knows it makes them better. ▣

The mist in this scene from *The Prestige* was accidental but powerful.

DANIEL ENGBER (@danengber) *wrote about the inventor of body plastination in issue 21.02.*

SPOILER ALERT! FLIP MAGAZINE TO READ.

trail for each object, as if stretching it in multiple dimensions. Faced with such a mind-bending design challenge—*he had to build the inside of a black hole*—most directors and designers would have given in and turned to CGI. But Crowley and Nolan wanted real substance: a set that actors could touch and interact with, something that existed outside of the photographic image.

Crowley tried to make a room with walls of one-way mirrors so its furniture would appear reflected into infinity—but that didn’t capture what he and Nolan wanted. They couldn’t find a solution, until one day in Iceland when production was suspended by a heavy storm and they found themselves trapped for hours in the hotel restaurant with visual effects supervisor Paul Franklin. There the three devised what Crowley now calls “an impregnable mesh of installation art”: a three-story framed structure, 90 feet by 60 feet by 45 feet, that contained multiple versions of the same room, with interior furnishings hand-sculpted to surreal dimensions so they would stretch across from one space into another.

But even with their similar aesthetics and comfortable collaboration style, Nolan can challenge Crowley’s methods. The hardest thing about *Interstellar* for Crowley was imagining time and space inside a black hole. “It was the first thing we talked about,” Crowley says, “and the last thing we managed to design.” Their goal was to create a room where time could visually unfold as a sort of con-

---

[3] More than 10,000 flights were canceled in the aftermath.

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A bot exits a landing craft on location in Iceland.

FIRST DIMENSION

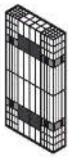
UNBOXED

INTERSTELLAR'S DECEPTIVELY SIMPLE DROIDS.

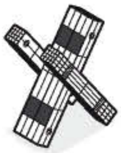
BY JASON KEHE

WHILE CHRISTOPHER Nolan was making *Interstellar*, he decided to show a model of the movie's bots to his kids. They were extremely disappointed. "That's not a robot," they told him. "That's a box." Well, it's true: Nolan's intelligent machines, which he dreamed up with production designer Nathan Crowley (see page 52), look for all the universe like slabs of metal. The main bot, named TARS (which doesn't stand for anything), might as well be a distant cousin of *2001*'s monolith. Then again, nothing in Nolan's world(s) is what it seems. "When I let my kids play with the model, open it up, see different combinations," he says, "they started getting really excited." Let's peek inside the box.

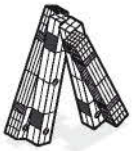
ROBOT CONFIGURATIONS



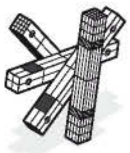
At rest



"Crutch walk"



Two-legged walk



"The wheel"

Locomotion
TARS is basically a robotic Kit Kat bar. His four "fingers" can execute a two-legged gait, a "crutch walk," a scissor kick, and a full-on four-legged gallop.

Appendages
When the bot articulates, his fingers can subdivide into smaller, identical appendages. In the movie, we see three subdivisions, but the CG team prepped up to five. By that point, the extremities were like toothpicks.

Personality
You could describe TARS as the film's comic relief. In collaboration with Nolan, actor Bill Irwin decided to play the character "somewhere between a marine company commander and a gym teacher."

Special Effects
F/x coordinator Scott Fisher, whose team built the eight robots used for production, estimates that 80 percent of the bot footage in the final cut was shot in-camera, no CG required. "When things fold out in a way that's impossible," he says, "your eye catches it and you know it's fake." CG was reserved for acts of extraordinary robotics, like when a bot named CASE turns into a massive asterisk and tumbles through water.

Materials
Weighing almost 200 pounds, TARS is an aluminum skeleton skinned in stainless steel. It took six weeks and about $20,000 to build. But a real-life TARS? "It'd definitely cost more," Fisher says. Accounting, ya know, for the whole AI thing.

Performance
TARS's dialog wasn't dubbed after the fact—Irwin recorded it live. But that's not all: He also operated the hydraulics that controlled the heavy machines. (Irwin is a few inches taller than TARS, which meant erasing his forehead in postproduction.) During filming in Iceland, Irwin had to work in thigh-deep water, and the robots' metal corroded so badly that two models had to be disassembled and rebuilt.

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Sam Smith, In the Lonely Hour

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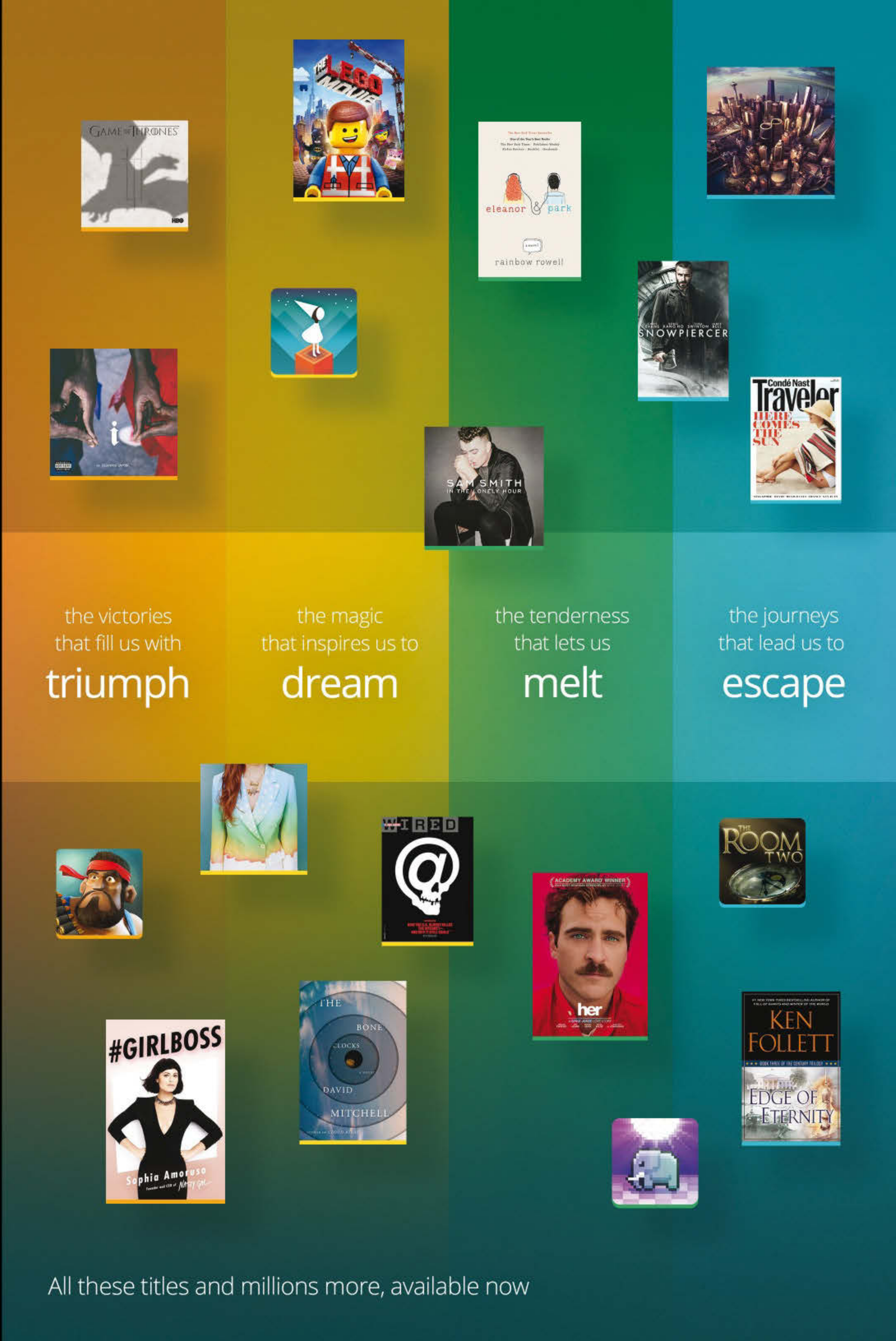
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that fill us with
triumph
the magic
that inspires us to
dream
the tenderness
that lets us
melt
the journeys
that lead us to
escape
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jennifer lawrence

OSCAR WINNER, FRANCHISE STAR, PRIVACY CRUSADER, BREATH OF FRESH AIR

"I don't like yes-people. I don't like lackeys. I don't like people when they fake-laugh at my jokes."

INTERVIEW: SAM KASHNER
PHOTOGRAPH: PATRICK DEMARCHELIER
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"When I was young, I thought I knew *everything*. Now, I'm not sure if I know *anything*."

INTERVIEW: LYNN HIRSCHBERG, *W* MAGAZINE
PHOTOGRAPH: PAOLA KUDACKI, *GQ*

lena dunham

MOTHER OF *GIRLS*, EMPOWERER OF EVERYWOMAN, EXPLICATOR OF THE ZEITGEIST

"I still go to a party and say something embarrassing to someone, and then write them a weird e-mail about it the next day, and then write them a text because I think they didn't get the e-mail. No matter what happens with your level of success, you still have to deal with all the baggage that is yourself."

INTERVIEW: NATHAN HELLER
PHOTOGRAPH: ANNIE LEIBOVITZ
VOGUE

channing tatum

AS *FOXCATCHER'S* OLYMPIAN, HE WRESTLES THOSE BRO-HIMBO-G.I. JOE ROLES TO THE MAT

"What I respect about this entire business is the hustle of it all and how many people have carved out their purposes in it. Somehow I carved out a place for myself."

INTERVIEW: CHRIS HEATH
PHOTOGRAPH: SEBASTIAN KIM
GQ

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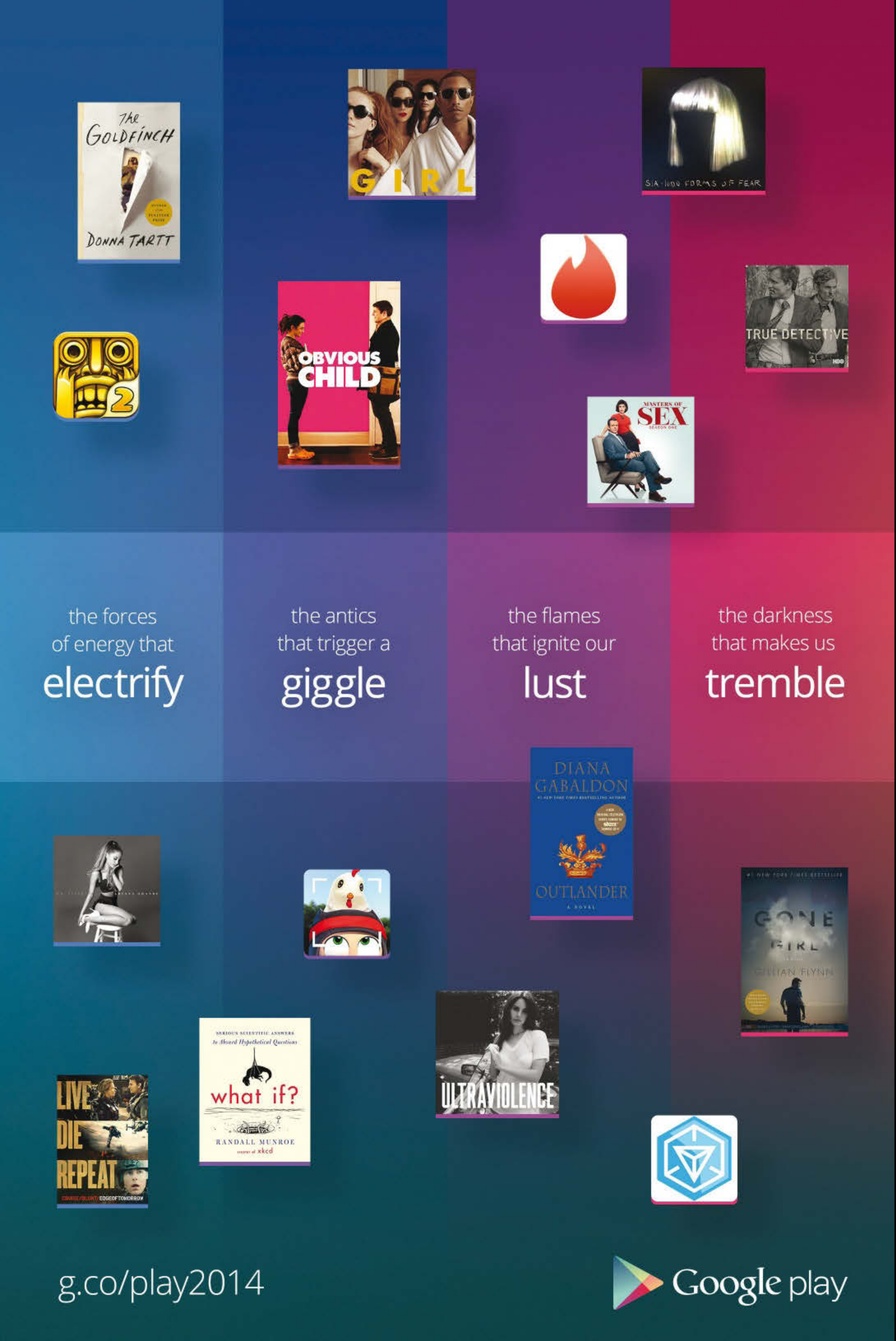

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that trigger a
giggle

the flames
that ignite our
lust

the darkness
that makes us
tremble

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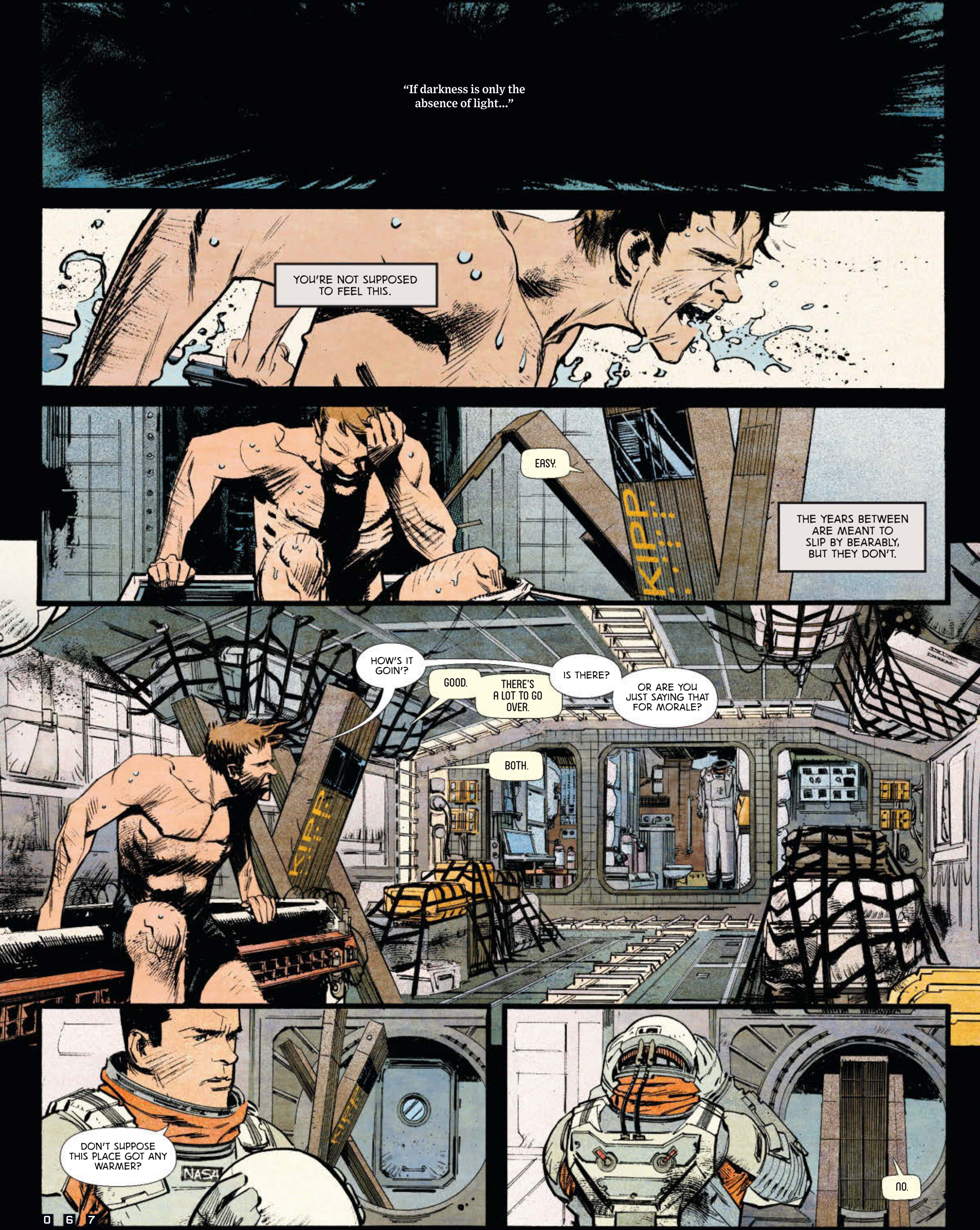
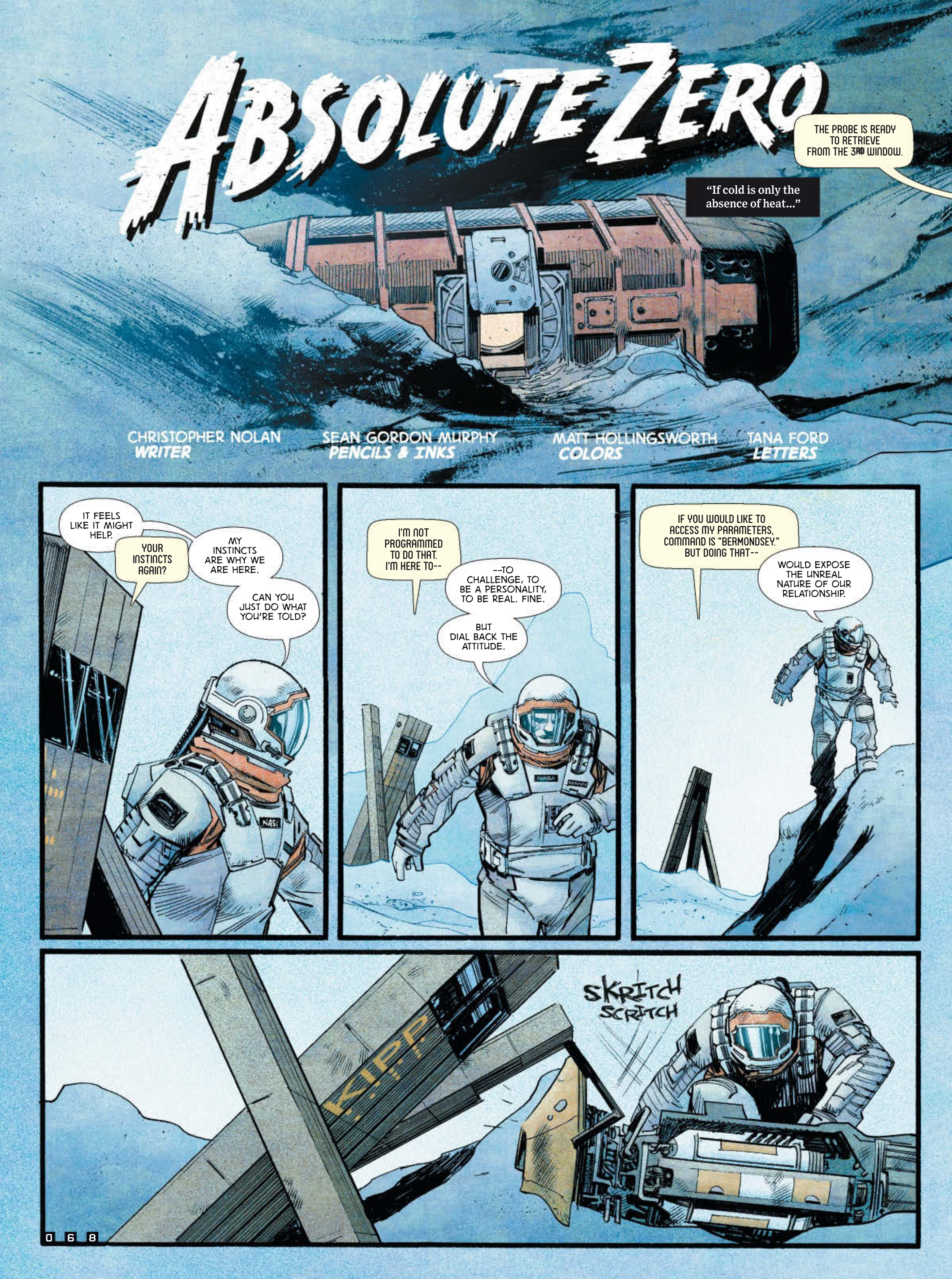
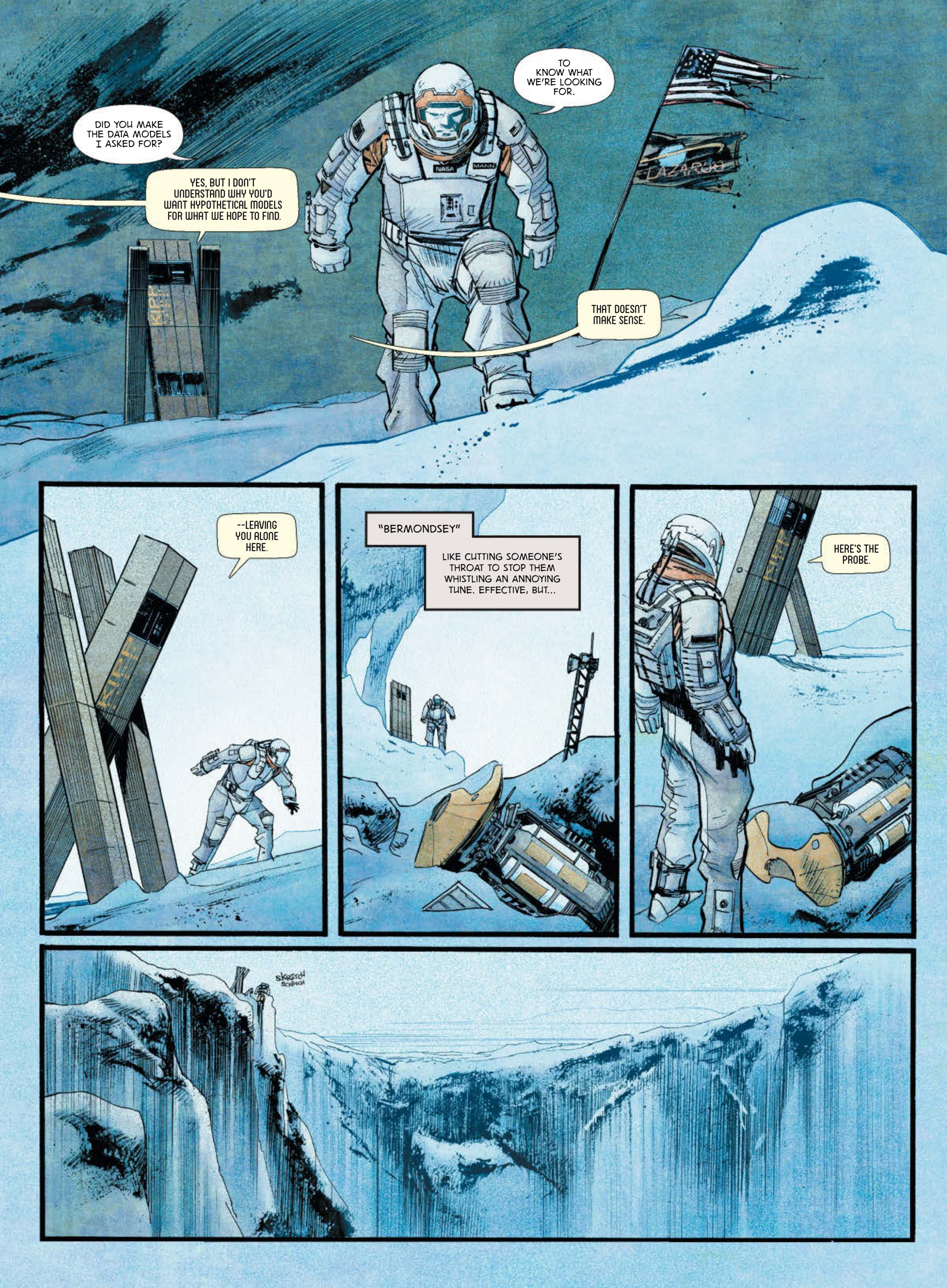
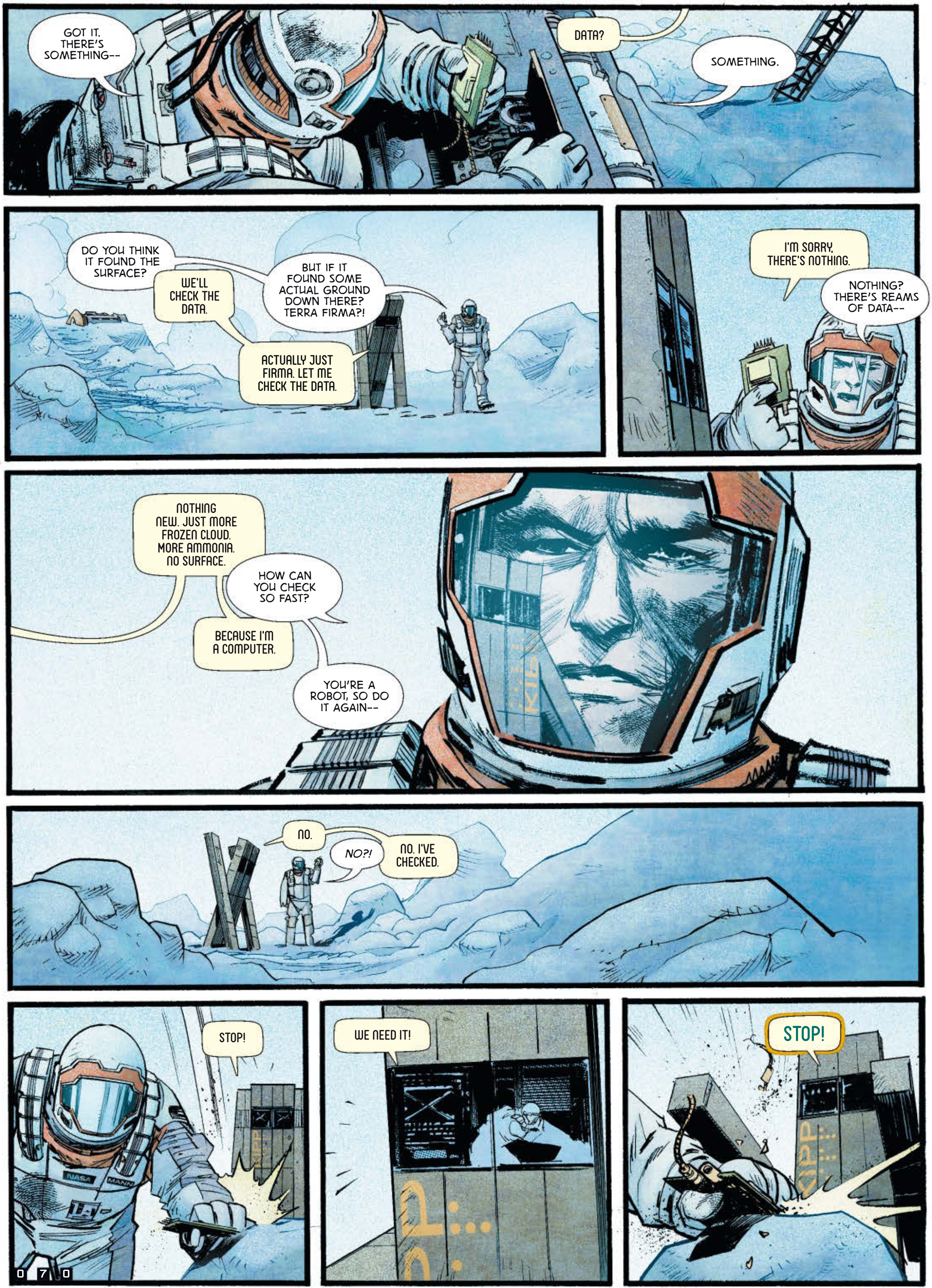

"If darkness is only the absence of light..."
YOU'RE NOT SUPPOSED TO FEEL THIS.
EASY.
THE YEARS BETWEEN ARE MEANT TO SLIP BY BEARABLY, BUT THEY DON'T.
KIPP
HOW'S IT GOIN'?
GOOD.
THERE'S A LOT TO GO OVER.
IS THERE?
OR ARE YOU JUST SAYING THAT FOR MORALE?
BOTH.
KIPP
DON'T SUPPOSE THIS PLACE GOT ANY WARMER?
NASA
NO.

ABSOLUTE ZERO

CHRISTOPHER NOLAN **WRITER**
SEAN GORDON MURPHY **PENCILS & INKS**
MATT HOLLINGSWORTH **COLORS**
TANA FORD **LETTERS**


THE PROBE IS READY TO RETRIEVE FROM THE 3RD WINDOW.
"If cold is only the absence of heat..."
IT FEELS LIKE IT MIGHT HELP.
YOUR INSTINCTS AGAIN?
MY INSTINCTS ARE WHY WE ARE HERE.
CAN YOU JUST DO WHAT YOU'RE TOLD?
NASA
I'M NOT PROGRAMMED TO DO THAT. I'M HERE TO--
--TO CHALLENGE, TO BE A PERSONALITY, TO BE REAL. FINE.
BUT DIAL BACK THE ATTITUDE.
NASA
MANN
IF YOU WOULD LIKE TO ACCESS MY PARAMETERS, COMMAND IS "BERMONDSEY." BUT DOING THAT--
WOULD EXPOSE THE UNREAL NATURE OF OUR RELATIONSHIP.
KIPP
SKRITCH SCRITCH


DID YOU MAKE THE DATA MODELS I ASKED FOR?
YES, BUT I DON'T UNDERSTAND WHY YOU'D WANT HYPOTHETICAL MODELS FOR WHAT WE HOPE TO FIND.
TO KNOW WHAT WE'RE LOOKING FOR.
THAT DOESN'T MAKE SENSE.
KIPP
NASA
MANN
LAZARUS
--LEAVING YOU ALONE HERE.
"BERMONDSEY"
LIKE CUTTING SOMEONE'S THROAT TO STOP THEM WHISTLING AN ANNOYING TUNE. EFFECTIVE, BUT...
HERE'S THE PROBE.
SKRITCH SCRITCH


GOT IT. THERE'S SOMETHING--
DATA?
SOMETHING.
DO YOU THINK IT FOUND THE SURFACE?
WE'LL CHECK THE DATA.
BUT IF IT FOUND SOME ACTUAL GROUND DOWN THERE? TERRA FIRMA?!
ACTUALLY JUST FIRMA. LET ME CHECK THE DATA.
I'M SORRY, THERE'S NOTHING.
NOTHING? THERE'S REAMS OF DATA--
NOTHING NEW. JUST MORE FROZEN CLOUD. MORE AMMONIA. NO SURFACE.
HOW CAN YOU CHECK SO FAST?
BECAUSE I'M A COMPUTER.
YOU'RE A ROBOT, SO DO IT AGAIN--
KIPP
NO.
NO?!
NO. I'VE CHECKED.
STOP!
NASA
MANN
KIPP
WE NEED IT!
STOP!
KIPP

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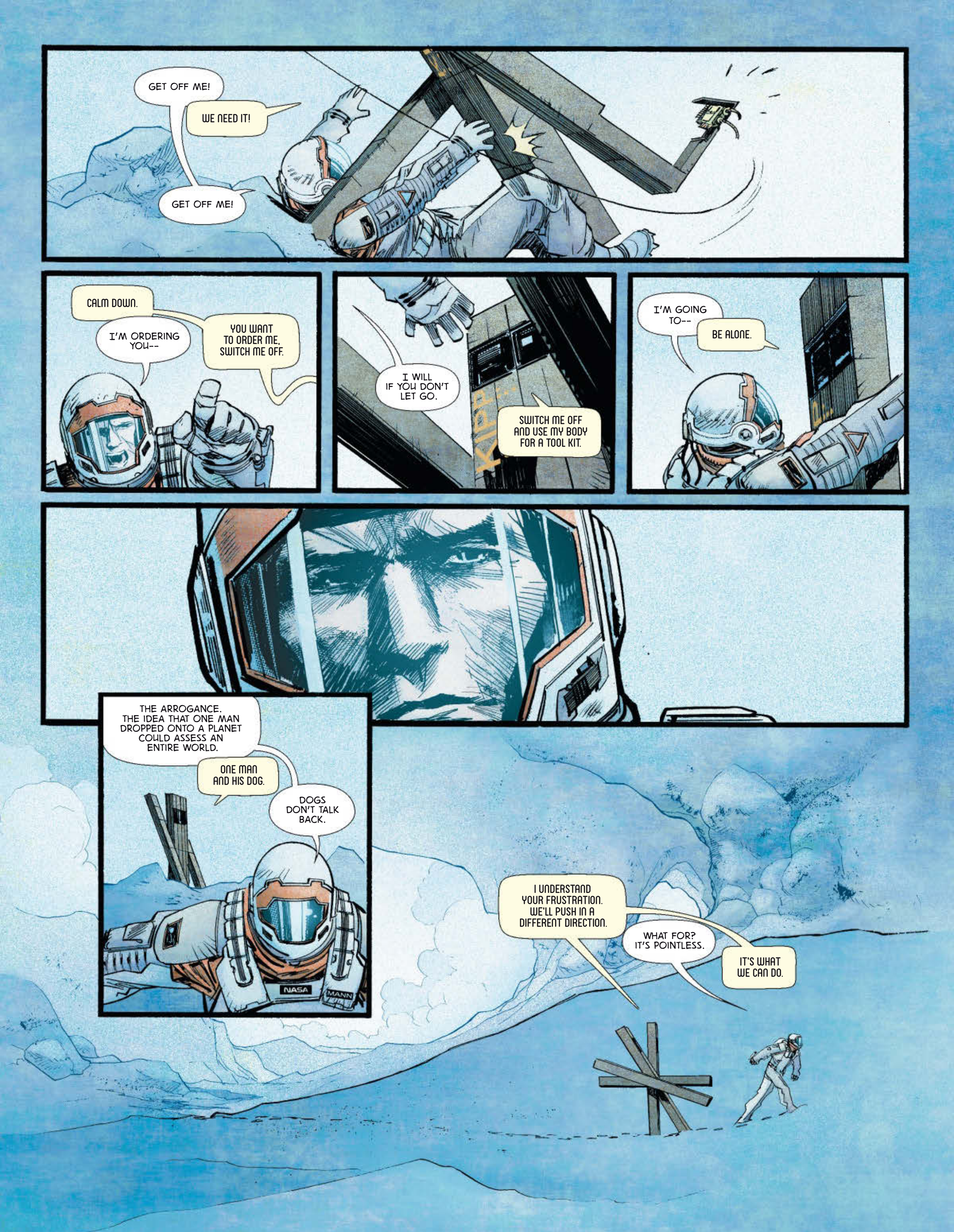
GET OFF ME!
WE NEED IT!
GET OFF ME!
CALM DOWN.
I'M ORDERING YOU--
YOU WANT TO ORDER ME, SWITCH ME OFF.
I WILL IF YOU DON'T LET GO.
SWITCH ME OFF AND USE MY BODY FOR A TOOL KIT.
KIPP...
I'M GOING TO--
BE ALONE.
THE ARROGANCE. THE IDEA THAT ONE MAN DROPPED ONTO A PLANET COULD ASSESS AN ENTIRE WORLD.
ONE MAN AND HIS DOG.
DOGS DON'T TALK BACK.
NASA
MANN
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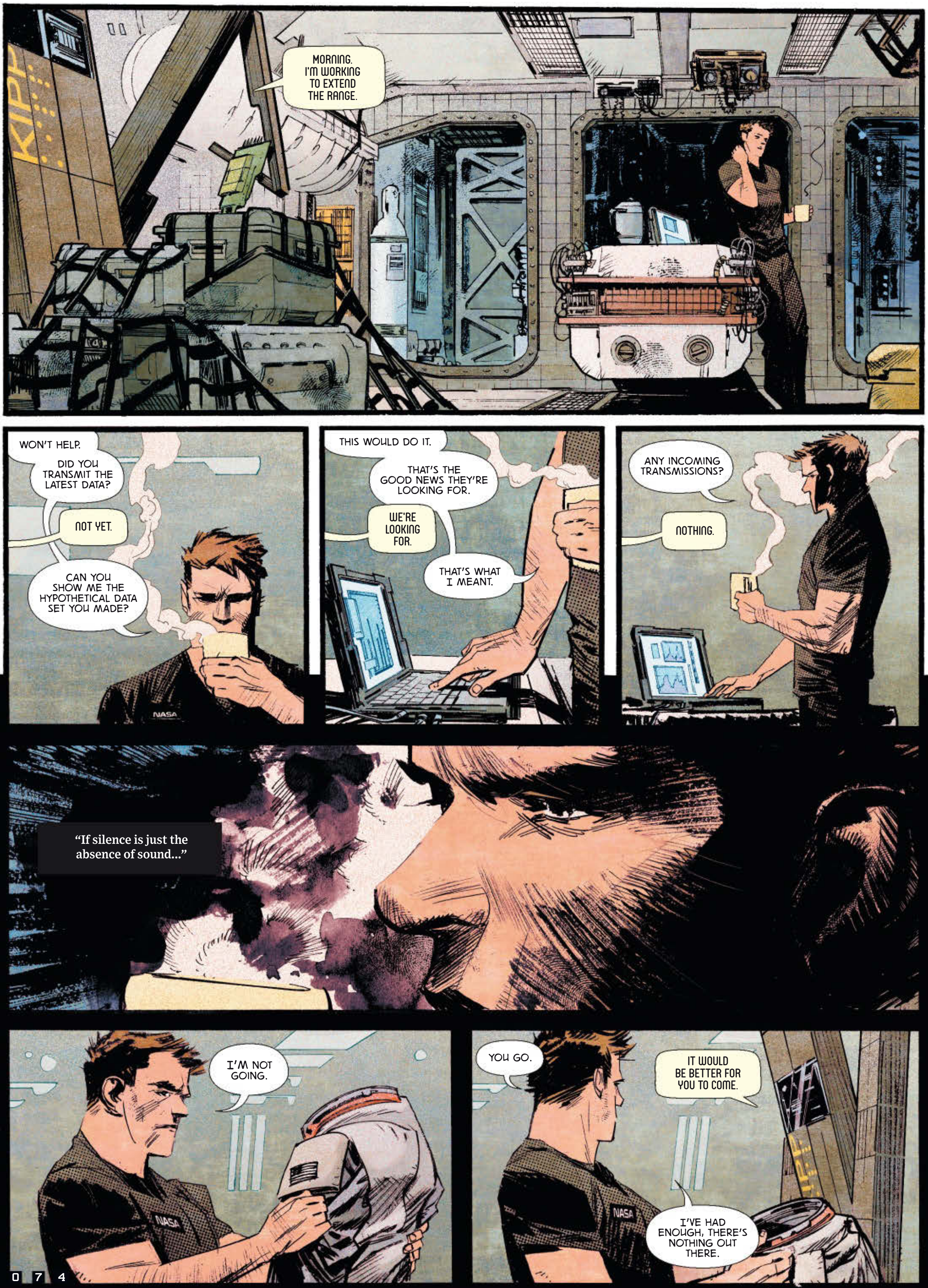
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DID YOU TRANSMIT THE LATEST DATA?
NOT YET.
CAN YOU SHOW ME THE HYPOTHETICAL DATA SET YOU MADE?
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THIS WOULD DO IT.
THAT'S THE GOOD NEWS THEY'RE LOOKING FOR.
WE'RE LOOKING FOR.
THAT'S WHAT I MEANT.
ANY INCOMING TRANSMISSIONS?
NOTHING.
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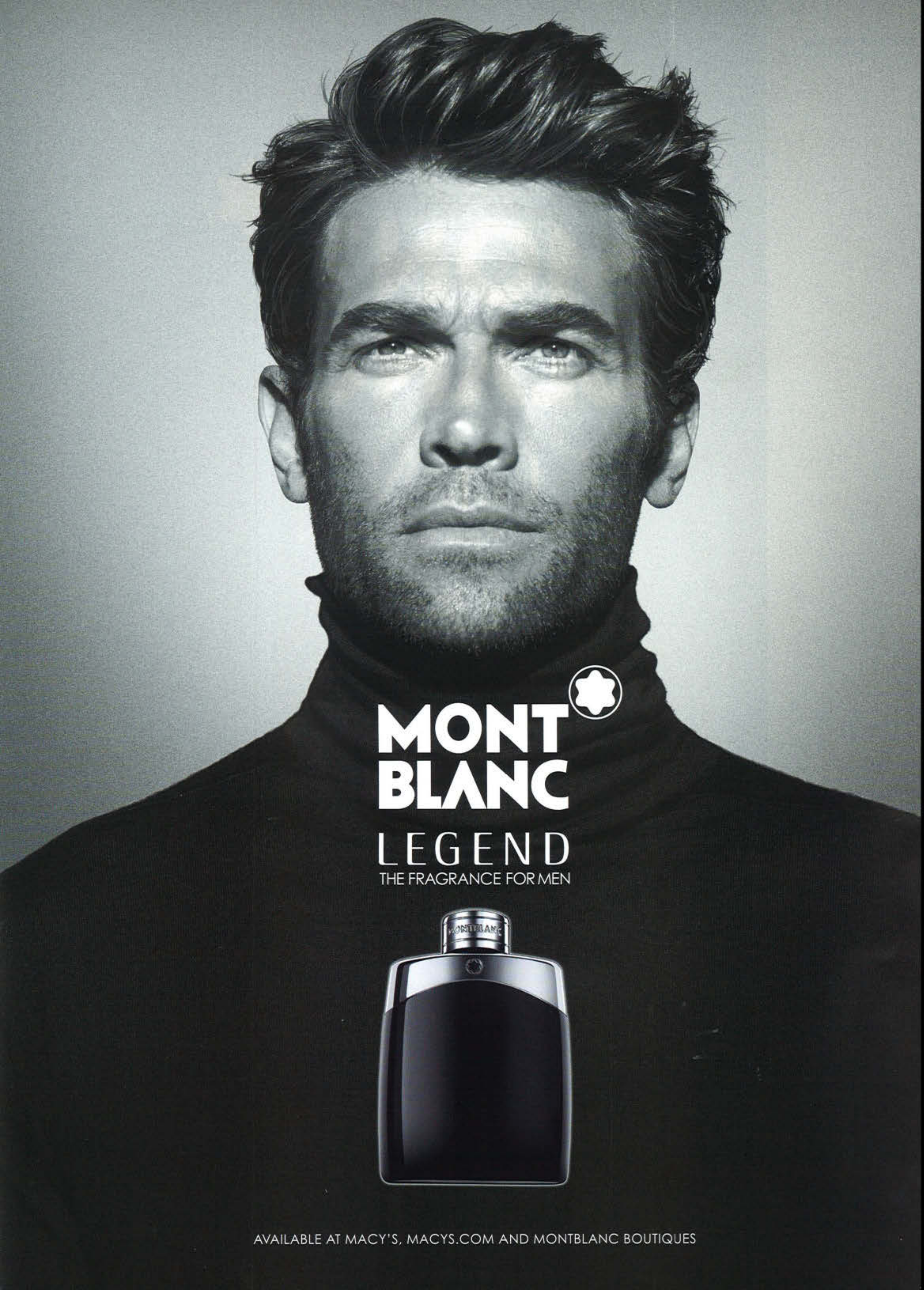

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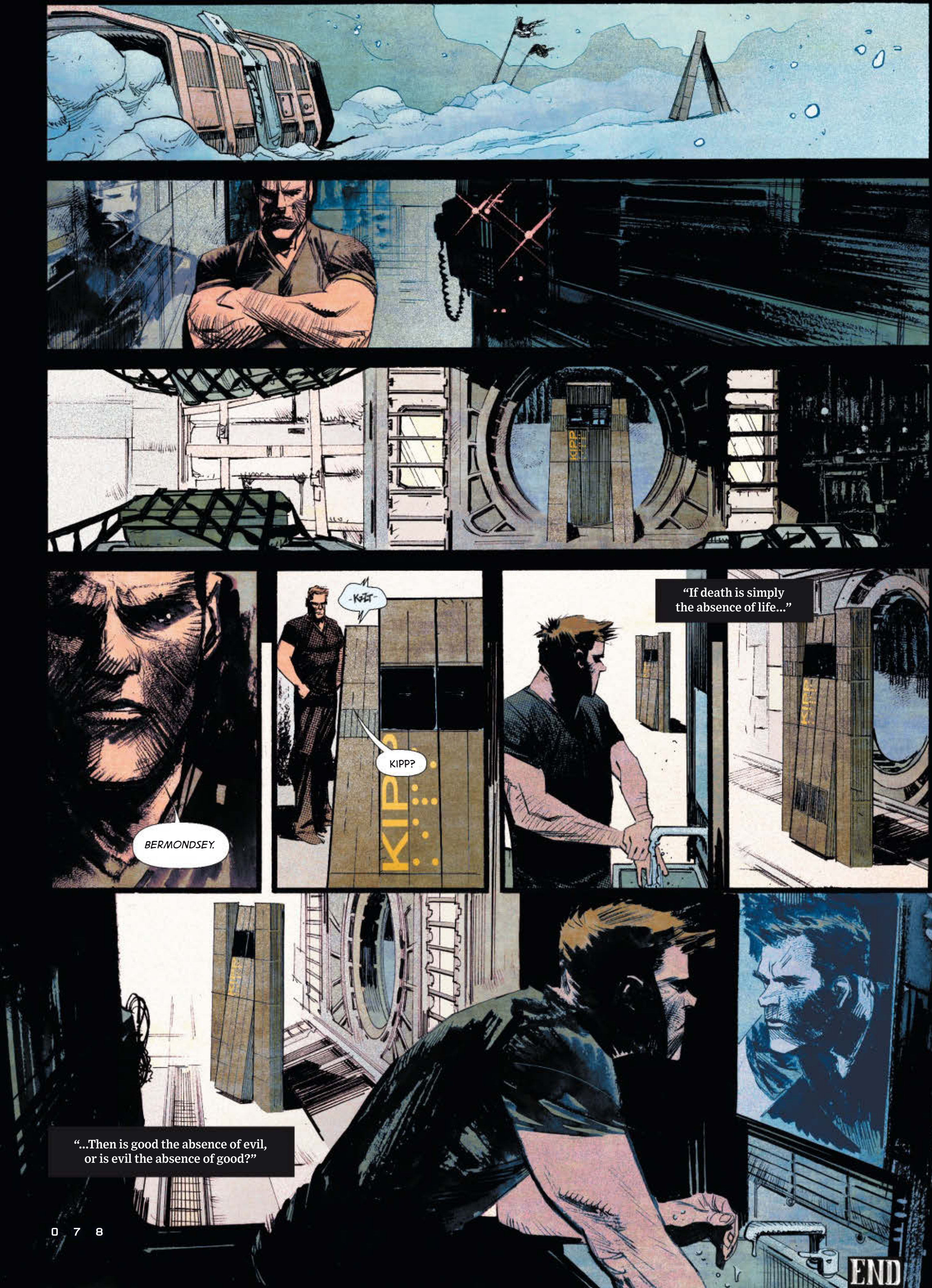
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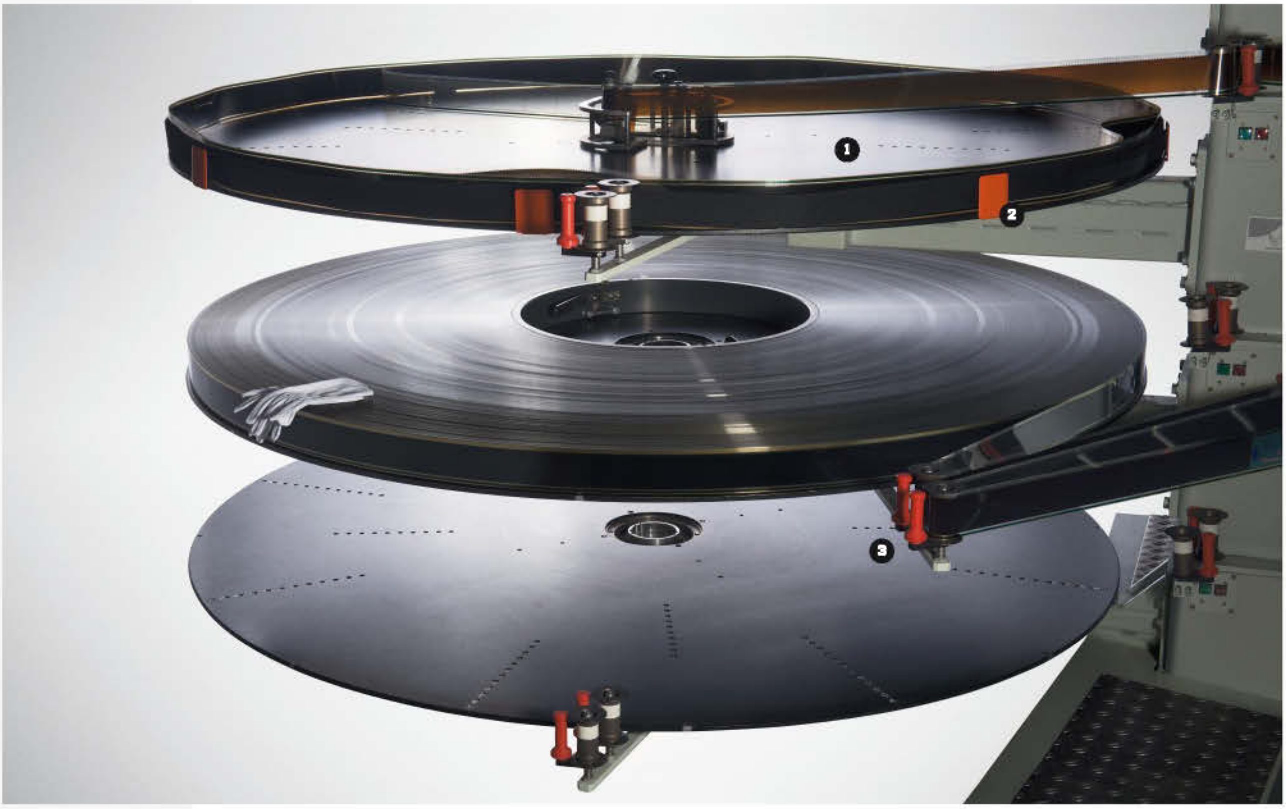
FIRST DIMENSION

BIGGER, LONGER, BETTER

HOW TO PUSH IMAX TO THE LIMIT ... AND BEYOND.

BY JULIA GREENBERG

PHOTOGRAPH BY CHRISTOPHER GRIFFITH



1. An exhibitor loads the film reel onto the platter and threads the film through a set of rollers that remove debris and smoothly feed the film into the projector.

2. The new clamps allow longer films to extend to the very edge of the platter without flying off.

3. As the movie plays, the film spools back onto the take-up platter, rewinding itself as it plays.

When it comes to *Interstellar*, the spaceship *Endurance* isn't the only thing going where no one has gone before—so is the movie itself. At 2 hours, 47 minutes, and 7 seconds, *Interstellar* is the longest Imax presentation ever. To screen it, all that film is wound up and placed on a 72-inch-diameter platter; fully loaded it weighs 600 pounds and takes a forklift to move. Director Christopher Nolan thinks it's worth it: 70-mm Imax film means higher resolution and crisper, clearer colors. But for years the limit on Imax running time was 2 hours, 30 minutes. "The diameter of the Imax platter dictates how long films can be," says David Keighley, chief quality officer at Imax. Then in 2009, when director James Cameron was producing a special-edition release of *Avatar*, he demanded more. So the company's engineers moved the clamp system that keeps the film on the platter from the top to the bottom, allowing more film to wrap around the outermost edge without flying off. The result? Cameron's cut came in at 2 hours, 46 minutes, and 54 seconds. Now *Interstellar* is topping that record by 13 seconds, including more than an hour of ultrasharp space footage shot with Imax cameras. Bigger isn't always better, but when it comes to Imax movies, we think it is.

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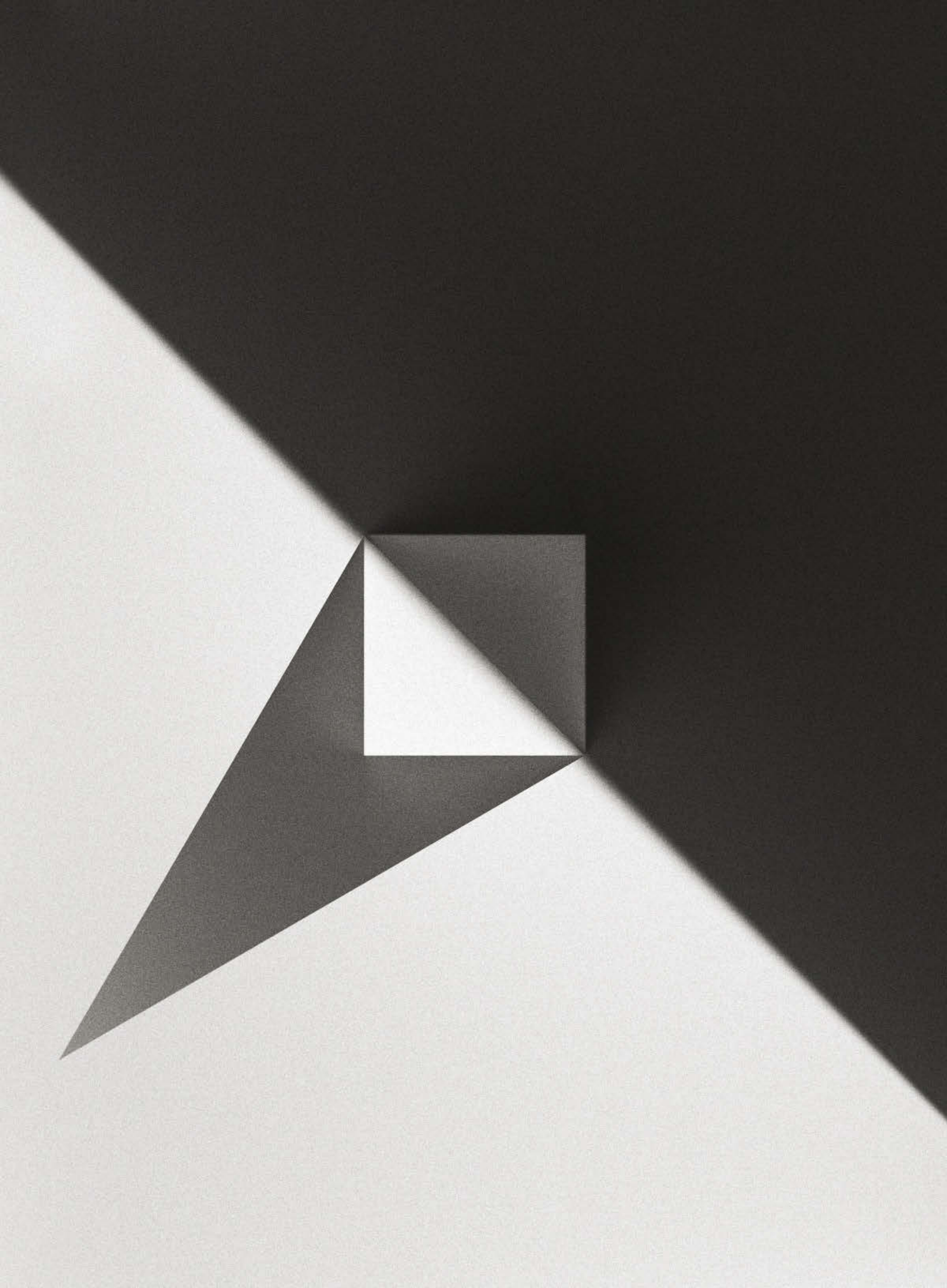
ORSON WELLES

SECOND DIMENSION: PLANE

INFLUENCES AND INSPIRATIONS,
FROM FLATLANDS TO OUTER LANDS.

“I CAN THINK



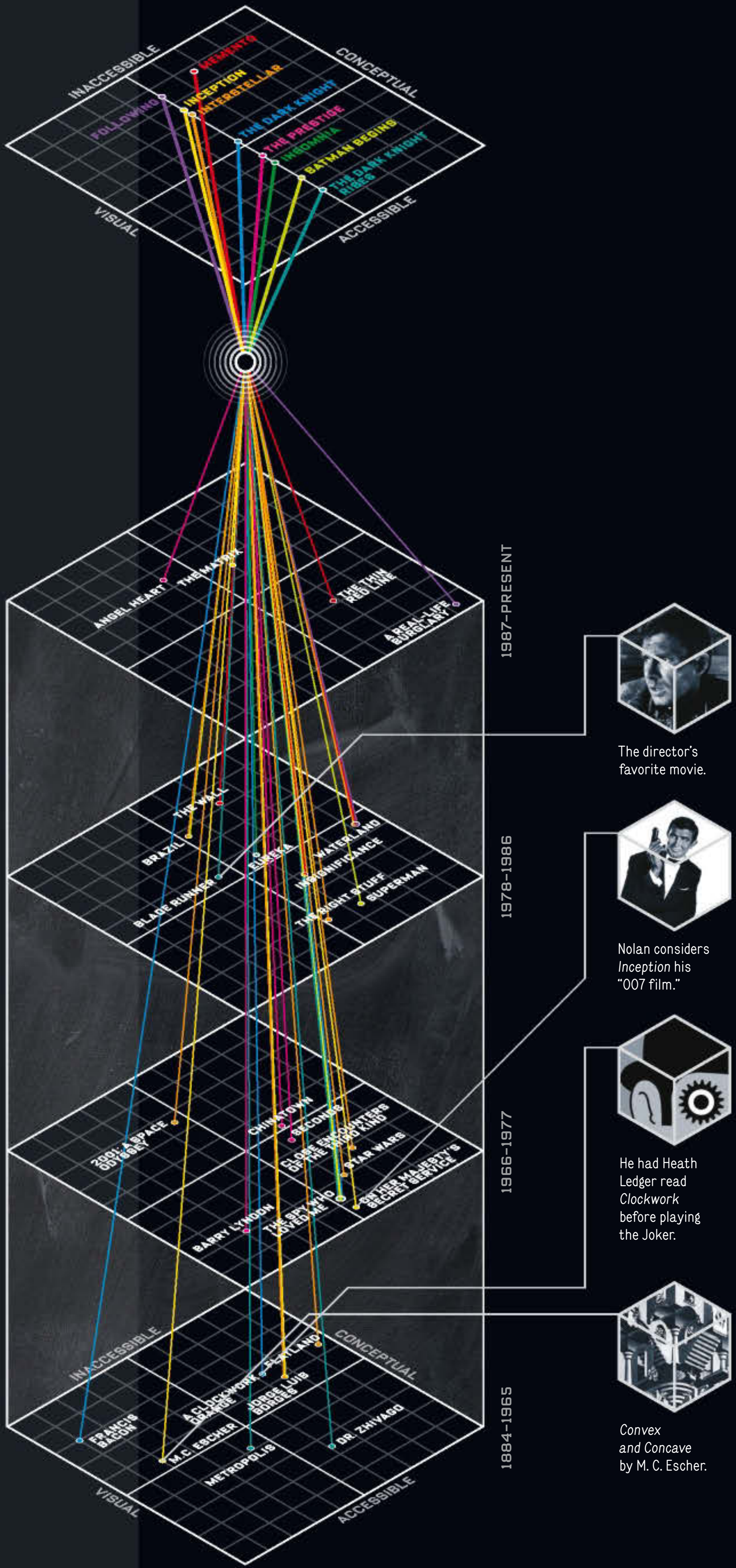
SECOND DIMENSION

DEEP IMPACT

CHARTING THE FAR-FLUNG INFLUENCES ON OUR GUEST EDITOR'S FILMS.

INFOGRAPHIC BY THOMAS POROSTOCKY

CHRISTOPHER NOLAN owes a lot to 1977: *Star Wars, Close Encounters of the Third Kind*, and *The Spy Who Loved Me*—three movies he often cites as major influences. But more important, 1977 was the year his dad took him to the theater to see *2001: A Space Odyssey*. The precocious kid instantly fell in love, and a career was born. "Movies become indistinguishable from our own memories," Nolan says. "You file them away and they become very personal." Those memories burrow through time and erupt in his films, so we journeyed back to see which works and artists have incepted him. —JORDAN CRUCCHIOLA AND JASON KEHE



The director's favorite movie.

Nolan considers *Inception* his "007 film."

He had Heath Ledger read *Clockwork* before playing the Joker.

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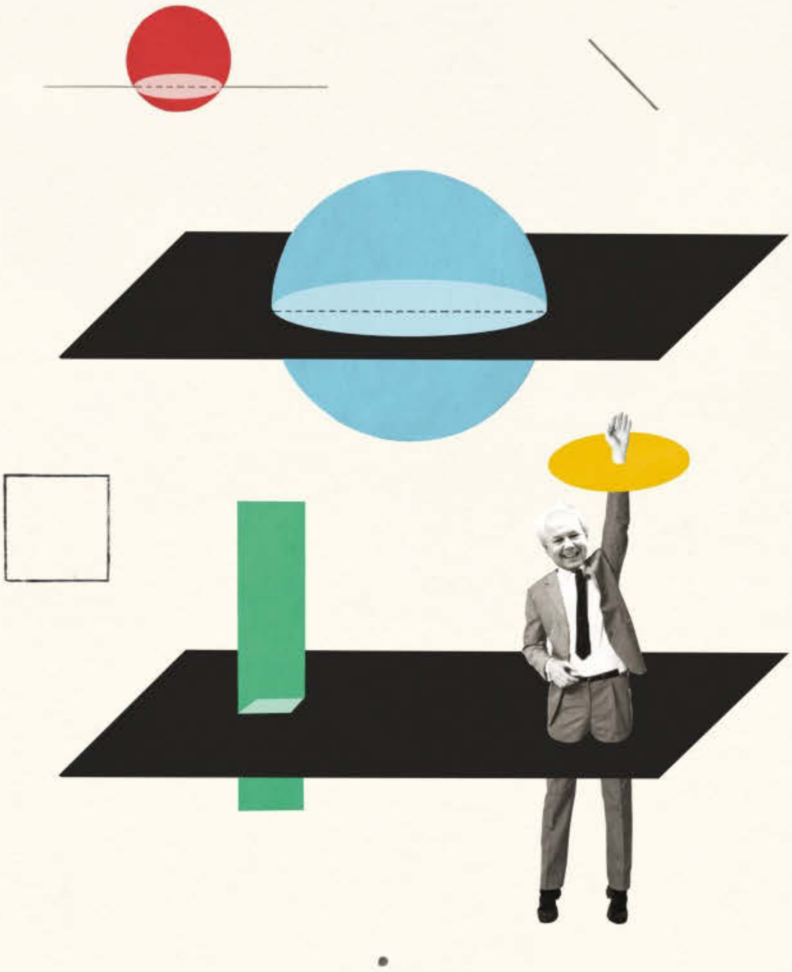
A TOUR OF FLATLAND

WHAT THE BOOK ABOUT LIFE AS A SQUARE CAN TEACH US.

BY JASON KEHE

ILLUSTRATION BY VALERO DOVAL



MATHEMATICIAN IAN STEWART wants us to see what he sees. Which is kind of a problem, because he's accustomed to envisioning some pretty impossible shapes: snowflakes in fractional dimensions, hypercubes in 4-D, 11-dimensional superstrings. So when the University of Warwick professor and author writes about these freaky geometries, he relies on an analogy—a way for us blockheads to understand realities above, below, and in between our three dimensions. His guide is a little mathematical fantasy he read over half a century ago: the cult classic *Flatland*. ¶ Written in the early 1880s by Edwin A. Abbott, the story follows A. Square, a regular quadrilateral who lives on a 2-D plane. He can't conceive of depth, but his perspective expands when a sphere visits him from 3-D Spaceland. Though Square can't experience all three of the sphere's dimensions, he can see it in cross-section as a circle of various sizes. That's the trick Stewart uses: By describing what it's like for a flat object to imagine a solid one, he can help us imagine an object in four dimensions. For instance, a crazy 4-D sphere (called a glome) might appear to us as expanding and contracting spherical cross-sections. "Starting with *Flatland*'s point of view," he says, "you find a way in."

Stewart considers *Flatland* one of the earliest works of popular science, a genre he's been writing in for decades (his latest book came out in October). In addition to an annotated *Flatland* and a trippy follow-up (*Flatterland*, natch), he has collaborated on four educational books about the science of Terry Pratchett's Discworld, in which wizards ponder the strange technology of Earth from a separate (magical) dimension.

In Flatland and Discworld, the act of removing yourself from your own reality allows you to understand it. And Stewart wants his readers to push that concept as far as they can. "How does the fourth dimension relate to the 11th?" Stewart asks. "We can crank up the analogy." Whatever you say, Professor—we'll keep an eye out for *Stringland*.

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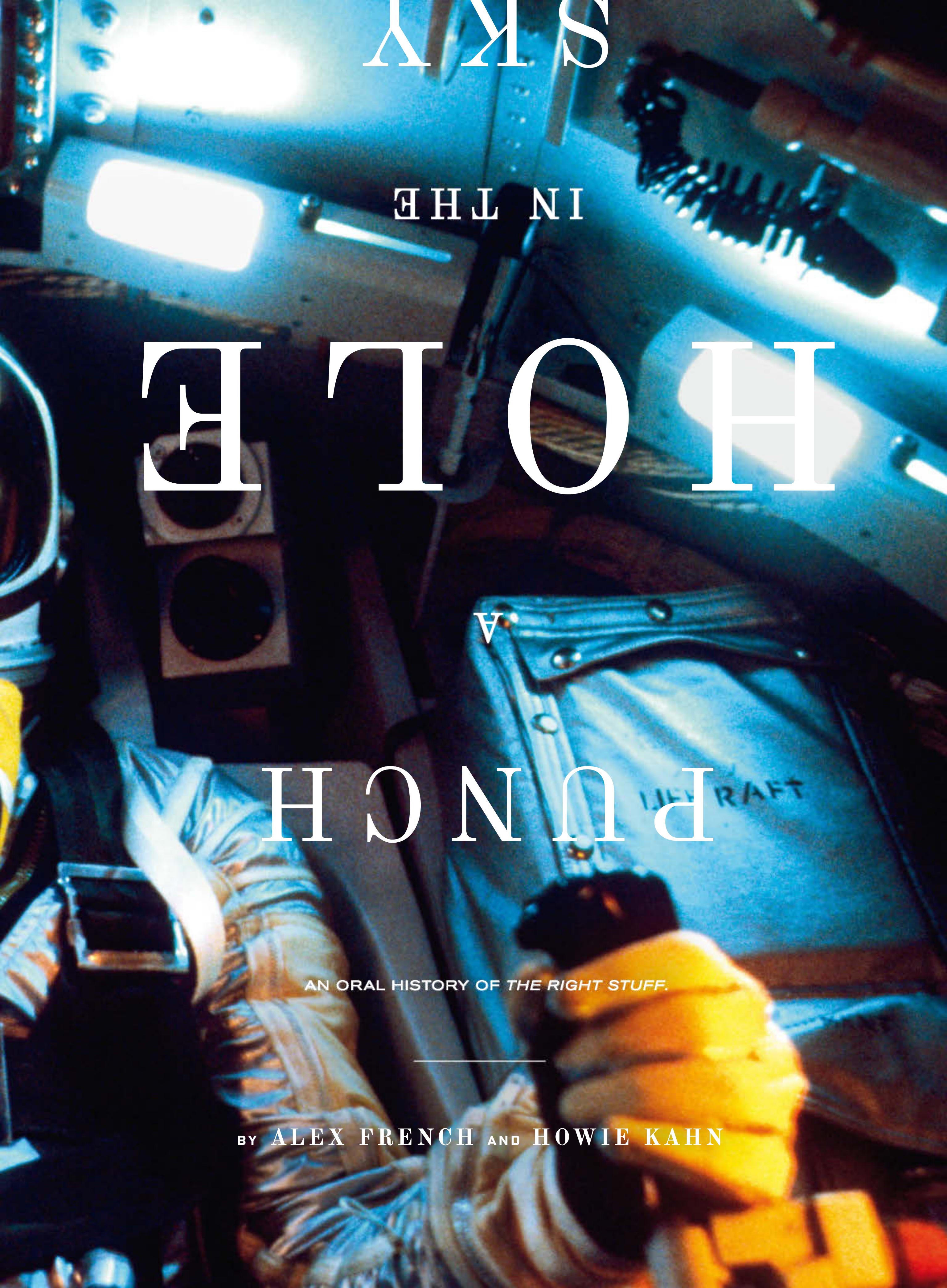
A RARE SPIRIT

BEFORE WRITER-director Philip Kaufman brought Tom Wolfe's book *The Right Stuff* to the big screen in 1983, onscreen astronauts were little more than alien quarry or asteroid bait. In Kaufman's hands, however, spaceflight became a far more human pursuit—a story not of external threats but inner resolve. With its three-hour-plus run time and unconventional structure, the film—which tells the story of test pilots like Chuck Yeager and Gordon Cooper as they break the sound barrier and launch toward the exosphere—was almost as daring as its subject. (Kaufman calls it "the longest movie ever made without a plot.") But it introduced an entire cinematic genre, what Quentin Tarantino has called the "hip epic," inspiring everyone from Michael Bay to James Cameron, who hired its cinematographer for *Titanic*. Its dialog has become a go-to signifier of human accomplishment; director Rian Johnson celebrated landing his *Star Wars* gig by tweeting a clip from the movie. "Phil really pulled it off," George Lucas says. None other than Christopher Nolan has called it "an almost perfect movie." ¶ Making it was an epic in itself. Its locations were hard-earned; its special-effects plan was largely reconceived during production; one man lost part of an ear on the set, another lost his life. But more than three decades later, *The Right Stuff* still resonates, a testament to the incredible feats of bravery, sacrifice, and intelligence of which humans are capable—and to the inherent absurdity of climbing into tin cans mounted on ballistic missiles and blasting into space.

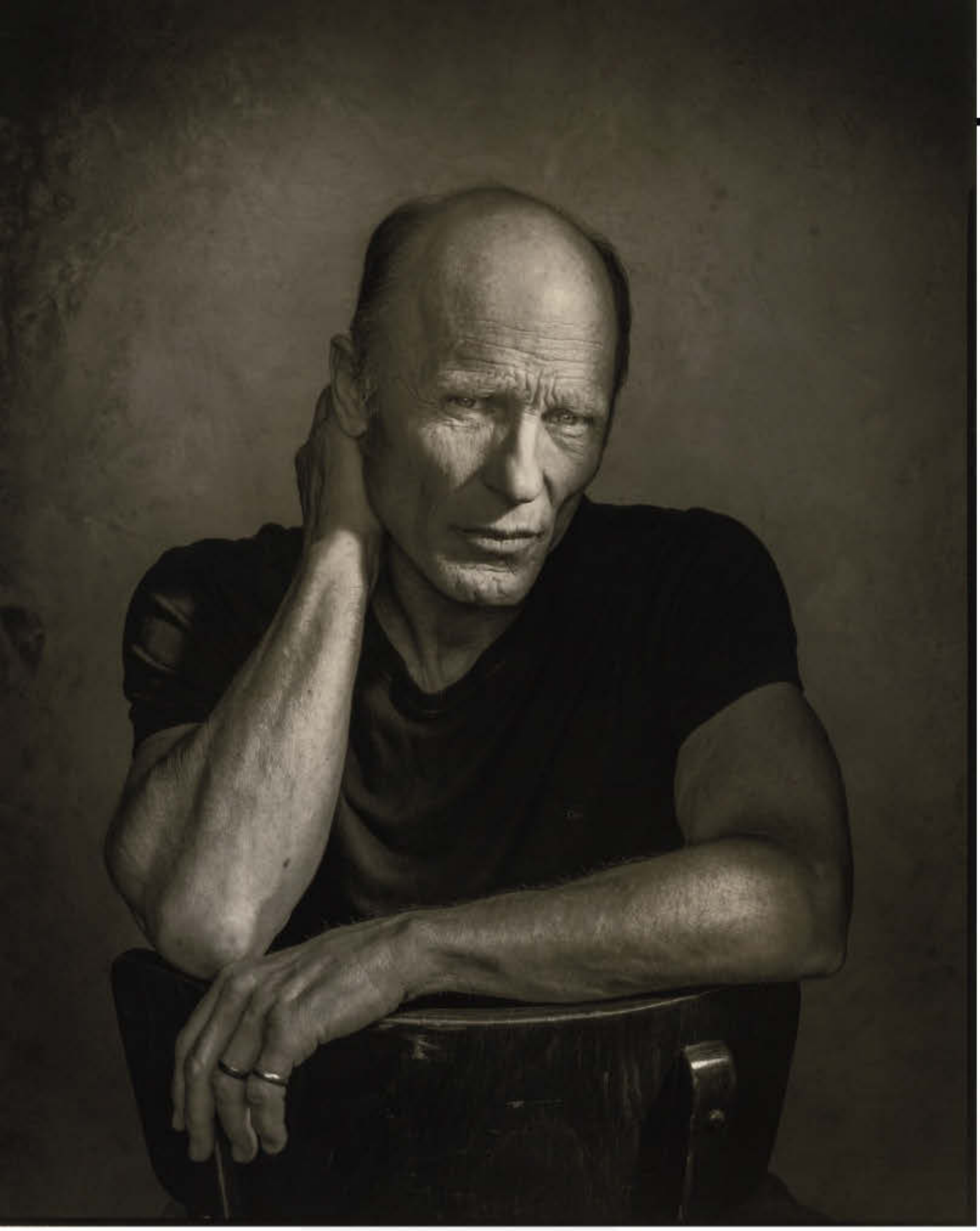


PUNCH A HOLE IN THE SKY

AN ORAL HISTORY OF *THE RIGHT STUFF.*

BY ALEX FRENCH AND HOWIE KAHN

DAN WINTERS



Ed Harris, above, looked so much like astronaut John Glenn that producer Robert Chartoff said, "Please, don't let this guy get hit by a car … until after the picture is made."

I.

"We Wanted to Make a Serious Film."

In 1979, Hollywood producers Irwin Winkler and Robert Chartoff (Rocky, Raging Bull) *paid $350,000 to purchase the film rights to* The Right Stuff, *Tom Wolfe's runaway best seller about the space race.*

CHUCK YEAGER (RETIRED GENERAL, U.S. AIR FORCE): Tom Wolfe started writing a book about the astronauts' early days. Through that, he discovered the Air Force test pilots who were doing the nitty-gritty work. We weren't getting free houses or notoriety. We were working our tails off for $250 a month. Many of us were dying in the process.

IRWIN WINKLER (PRODUCER): There was a competition with Universal to buy Tom Wolfe's book. They wanted it for John Belushi as a comedy.

ROBERT CHARTOFF (PRODUCER): Like the *Airplane* series.

WINKLER: We wanted to make a serious film. We hired Bill Goldman to write the screenplay.

CHARTOFF: Probably the hottest writer in Hollywood.

WINKLER: But Bill's script didn't include the Chuck Yeager character, the epitome of "the right stuff."[1] So we started looking for other writers.

GEORGE LUCAS: I was born and raised in the Bay Area, so when I got out of film school at USC I wanted to come back. Francis Coppola wanted to get out of Hollywood, so the two of us, we decided we'd move to San Francisco. There was a cadre of people here who were making movies, but more with a San Franciscan sensibility than a Hollywood sensibility. Phil Kaufman was living here. He worked on *Raiders* for about a week. [*Laughs*.] He came up with the idea for the ark.

PHILIP KAUFMAN (WRITER, DIRECTOR): When I read *The Right Stuff* I was just amazed. I wound up outlining a script, and when Chartoff and Winkler asked me to write it, I wrote the first draft in about eight weeks. I really wanted to find that Tom Wolfe quality, the craziness of the American circus at that time.

WINKLER: We gave Phil's script to the Ladd Company, ensconced at Warner Bros.

GARY GUTIERREZ (SUPERVISOR, SPECIAL VISUAL EFFECTS): Phil Kaufman was looking to storyboard the movie for a presentation to Alan Ladd Jr. in LA. It was an enormous job; we created around 1,800 panels. We laid out the storyboards on eight or 10 tables in a conference room and then Phil told the story, walking Ladd around the room. Whenever he'd finish a couple of tables, we'd lay out more. It took several trips around the room.

ALAN LADD JR. (PRESIDENT, THE LADD COMPANY): I said, OK, let's make the movie!

GUTIERREZ: Chuck Yeager became a technical consultant. He was very helpful.

YEAGER: Hollywood is in the business of make-believe. I didn't just walk out and fly the X-1 supersonic. It took unpowered flights and then nine powered flights.

GUTIERREZ: He would look at stuff and say, "Well, that's not exactly how it happened, but I know you fellas have to flower it up."

---

[1] Yeager was the first pilot to break the sound barrier, on October 14, 1947.

PREVIOUS SPREAD: EVERETT COLLECTION; HARRIS: GROOMING BY LOUISE MOON

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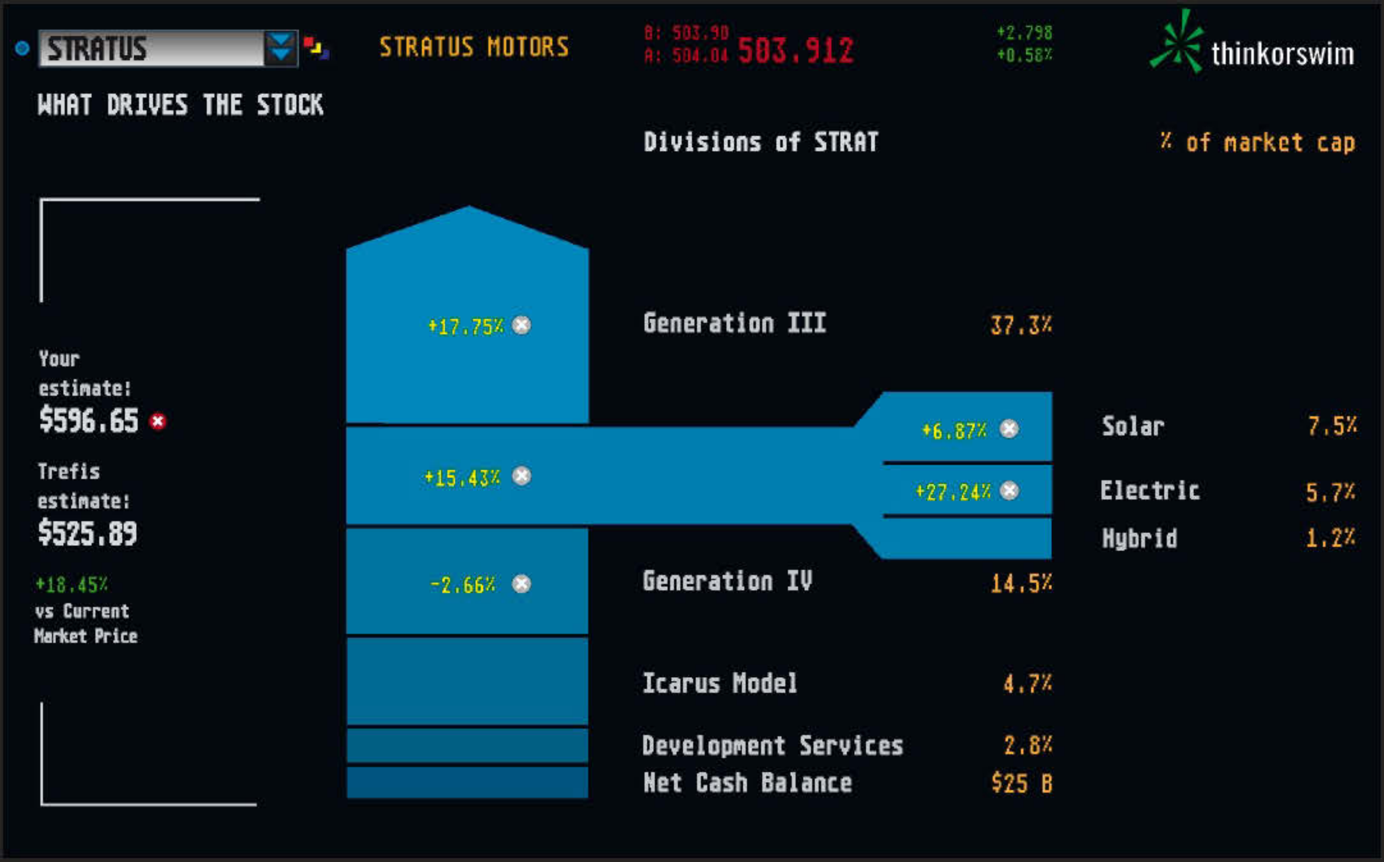

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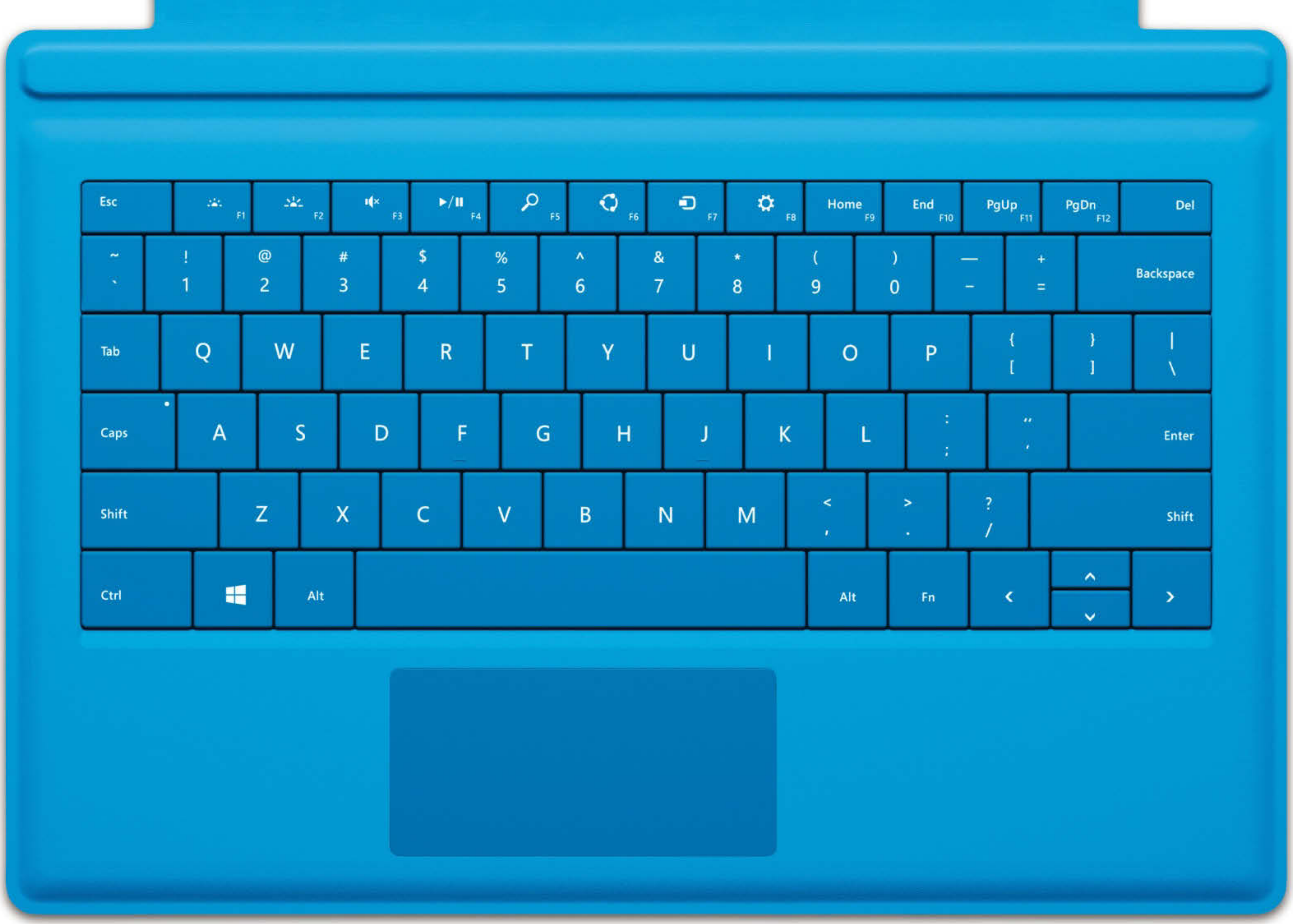
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Alphonso Flournoy
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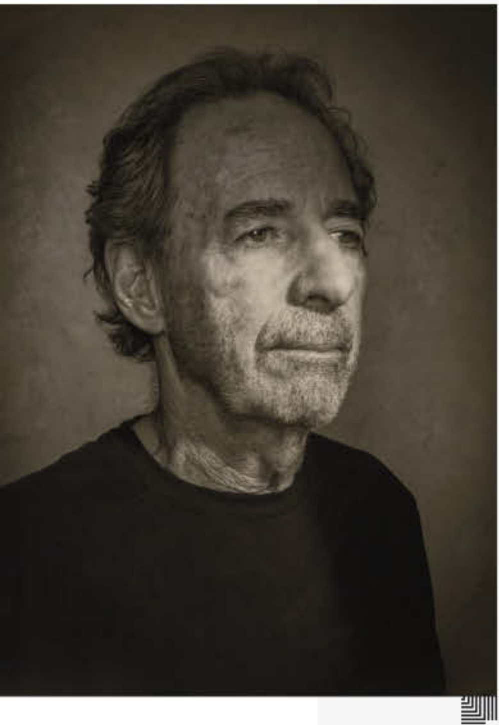

DAN WINTERS

Harry Shearer and Jeff Goldblum played recruiters. "Our characters had no written lines," Shearer says. "Phil said, 'You and Jeff improvise. Hopefully it will be funny.'"

> “I REALLY WANTED TO FIND THAT TOM WOLFE QUALITY, THE CRAZINESS OF THE AMERICAN CIRCUS AT THAT TIME.”
>
> PHILIP KAUFMAN

II.

“I Felt Like It Was Ridiculous to Play a Living Person.”

Ladd gave Kaufman a modest budget to make the film, which meant it would have to be made without any bankable stars and with salary caps.

ED HARRIS (JOHN GLENN): I read for Phil Kaufman and wasn't very happy about how it went. Walking out, I hit the wall pretty hard. Phil saw me do that and said, “Oh, the guy's got spunk.”

CHARTOFF: When Ed Harris walked in, we couldn't believe that such a person existed. He was not only a wonderful actor but looked so much like John Glenn. I said to Phil, “Please, don't let this guy get hit by a car. At least not until after the picture is made.”

HARRY SHEARER (RECRUITER): Jeff Goldblum's and my characters had no written lines. They weren't in the book. Phil basically just said, “You and Jeff improvise. Hopefully it'll be a little funny.”

KAUFMAN: I had my mission, but I also wanted to be entertained.

JEFF GOLDBLUM (RECRUITER): Mr. Philip Kaufman had me in *Invasion of the Body Snatchers* in 1978. I'd do anything with him.

MARY JO DESCHANEL (ANNIE GLENN): Annie Glenn was already cast, but the actress asked for more money and fell out. So I didn't know it when I went in, but they were looking for someone.

KAUFMAN: I was alone when Dennis Quaid (Gordon Cooper) came in. I was manning the camera, but I didn't really know how it worked. Dennis said, “I know that camera. I've got exactly this kind of camera.” I pressed the button. “It's red and flashing, does that mean it's on?” He said, “Yeah, that's it.” So then Dennis did a phenomenal reading. A couple hours later Chartoff and Winkler came in and I said, “Let's look at it.” Of course Dennis was wrong. The camera was off. One of the greatest auditions I'd ever seen was lost to history.

FRED WARD (GUS GRISSOM): I was asked to play another astronaut at first. But then Phil asked me to read for Gus Grissom. I'd been in the Air Force when I was young, as an airborne radar technician in Goose Bay, Labrador, during the cold war.[2] These astronauts were big people at the time.

YEAGER: Some of my friends played extras, such as Korky Kevorkian, a pilot and fruit farmer from Reedley, California. I played a bartender.

KAUFMAN: We started looking around for someone who could play Yeager. Then my wife, Rose, and I went to a poetry reading in San Francisco and Sam Shepard was reading. Rose poked me and said, “There's your guy.” I said, “For what?” She said, “Yeager.” Sam had a cowboy quality to him. He was Gary Cooper.

SAM SHEPARD (CHUCK YEAGER): Phil offered the part to me a few times, and I refused. I felt like it was ridiculous to play a living person. I knew Chuck and I didn't feel like I was him at all.

KAUFMAN: I slid the script under Sam's door in LA.

SHEPARD: He kept hounding me about it. And I did like Phil a lot, and I liked a lot of the actors I'd known through theater and stuff, like Ed Harris and Freddie Ward. So I thought, well, maybe it wouldn't hurt to do it.

ALEX FRENCH (@FrenchAlexM) *and* **HOWIE KAHN** (@howiekahn_) *have written numerous oral histories together. This is their first feature for* WIRED.

---

[2] “We'd have to go out at night and load missiles,” Ward says.

GROOMING BY LOUISE MOON; GOLDBLUM PHOTOGRAPHED AT CHATEAU MARMONT

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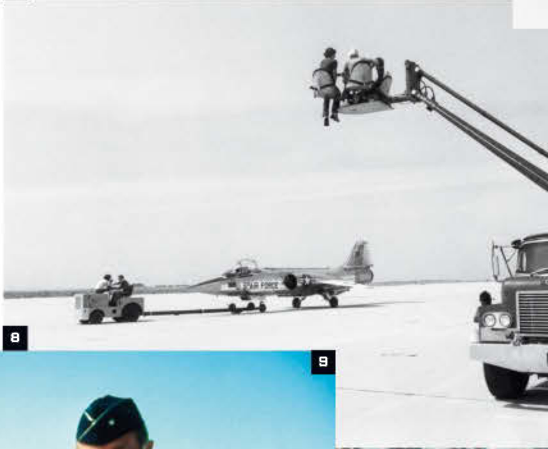
1 Dennis Quaid as Gordon Cooper 2 Chuck Yeager (top) with Arthur Murray and the Bell X-1A in 1953 3 Sam Shepard as Yeager 4 Shepard's Yeager again, in the spotlight 5 The Mercury 7 crew, as seen in the movie 6 Out of their space suits: (L-R) Gus Grissom (Fred Ward); Cooper (Quaid); Deke Slayton (Scott Paulin); John Glenn (Ed Harris); Scott Carpenter (Charles Frank); Alan Shepard (Scott Glenn); Wally Schirra (Lance Henriksen) 7 Cinematographer Caleb Deschanel 8 Filming at Edwards Air Force Base 9 Shepard and the real Chuck Yeager 10 Yeager getting out of a B-29 11 The film's pilots before their flight 12 A hero's welcome for Glenn (Harris)



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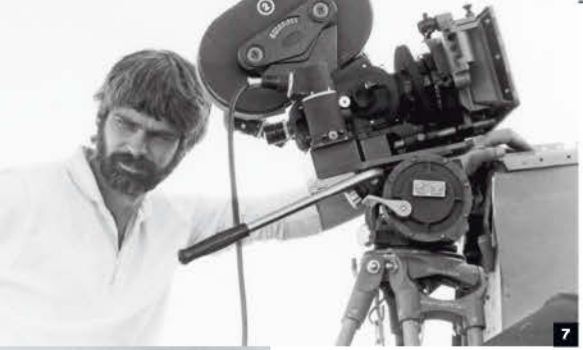

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12

III.

"Make It Like They Did in the Old Days."

Kaufman wanted his audience to feel the adrenaline rush that early test pilots experienced as they chased the sound barrier, as well as the violence inherent in breaking free from, and reentering, Earth's atmosphere.

GEOFFREY KIRKLAND (PRODUCTION DESIGNER): Phil got this amazing collection of research from NASA and the Navy. He set up a library in his trailer.

PHILIP KAUFMAN: Research went on in every area, all through the movie. When the actors showed up, each of them got a book that we had prepared with 30 to 40 pages on each character—every damn thing we could find.

PETER KAUFMAN (PRODUCTION ASSISTANT): I'd go to the Soviet embassy in San Francisco and they would give me footage of Star City. They were really helpful, the Russians. And we got footage from the Jet Propulsion Laboratory and the Air Force that hadn't been widely seen.

PHILIP KAUFMAN: We combined the great NASA footage with pieces that were built on the set. We were pioneering in that kind of insertion of actors into historical events. For example, we combined footage of the real Alan Shepard being loaded into the capsule with Scott Glenn doing it on the stage. We had Scott Glenn shaking hands with Kennedy; they did the same thing in *Forrest Gump* and made a big thing out of spending a million dollars to do it. We did that in one afternoon.

KIRKLAND: One day we went to the model shops to see the first shots of the supersonic jet. We had a production team out there, a whole unit unto themselves. They'd been working for six months making these amazing models. Every little rivet had a little bit of grime.

GUTIERREZ: We called our motion control system the Cruciflex—it allowed the camera to pan 360 degrees, pitch, and roll three times. You could shoot, say, the X-1 in front of a blue screen, and the camera would travel toward the model, giving the impression that the X-1 was moving toward the camera.

PHILIP KAUFMAN: We discovered that the motion control effects George was doing on *Star Wars* didn't create the grittier effect we wanted.

CALEB DESCHANEL (CINEMATOGRAPHER): Getting to outer space can be violent.

GUTIERREZ: "Make it like they did in the old days" became our marching orders.

CALEB DESCHANEL: In the scenes where Yeager is trying to break the sound barrier, Phil rear-projected footage from an experimental filmmaker to give a sense of what it was like.

GUTIERREZ: We did various kinds of shaky-cam movement to give it a sense of urgency. We attached a vibrator to the lens or a power drill to the camera mount to make it all move like crazy.

CALEB DESCHANEL: At one point I shook the camera so hard, I gave my operator a black eye.

RANDY THOM (SOUND RERECORDING MIXER): For the plane crashes, I went to Twentynine Palms Marine base to record the sound of a bomb detonating. I had to sign several reams of paper saying my family wouldn't sue if I got hurt.

SHEPARD: We had a model of the X-1 in the hangar. We had these rigs that shook the hell out of us. It wasn't a simulator. It was much more primitive. It was like a milk shake apparatus.

CALEB DESCHANEL: When Yeager goes up to break the sound barrier, you look down and you see the desert beneath; we had giant sheets of butcher paper with desert scenes painted on them and somebody was pulling the paper very slowly underneath the model so it would feel like you were at 20,000 feet with the Earth moving below.

CHARTOFF: Today it would be CGI.

KIRKLAND: We shot the sequence where Gus Grissom bails from his capsule in Half Moon Bay, within sight of Mavericks. You think of the Pacific as being calm, but it can be ugly.

WARD: I had a wet suit on under my flight suit, in pretty cold water. And then they picked me up, dangling by a rescue noose. It's a tragic scene.

PHILIP KAUFMAN: It was very dangerous. What a testament to Fred. Fred almost died in the water.

WARD: Grissom actually died in a prelaunch test. I heard the recording of the incident.

PHILIP KAUFMAN: Gus was a fucking hero.

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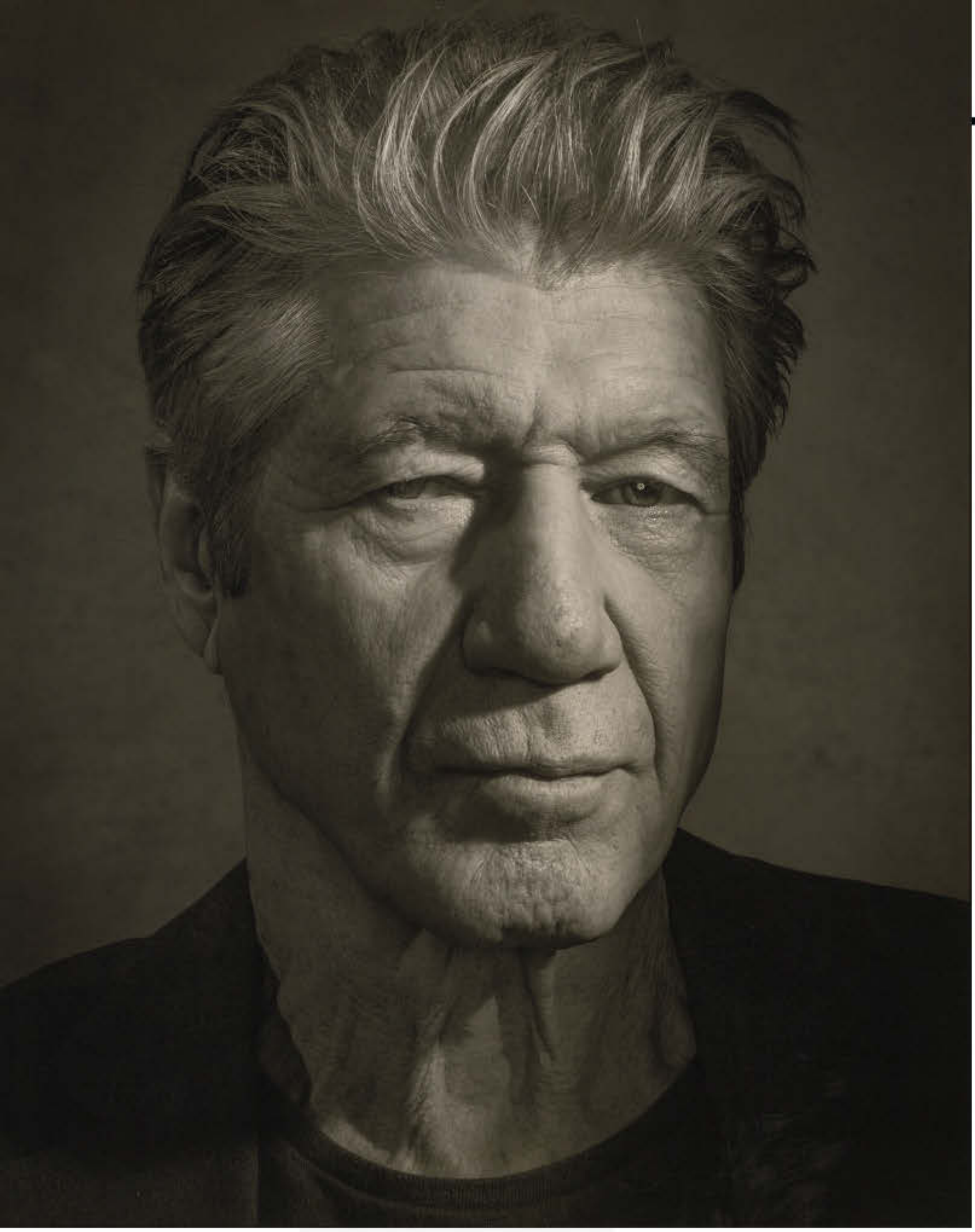

DAN WINTERS

Fred Ward played Gus Grissom, who would later die in the launchpad fire of Apollo 1. "Gus was a fucking hero," Kaufman says.

IV.

"We Really Had the Run of the Place."

Kaufman and his crew resisted cutting-edge special effects, preferring to make the film as realistic as possible. But that quest for authenticity led to some setbacks.

WINKLER: We had trouble getting permission from the Pentagon and NASA to use their facilities. John Glenn was a senior senator and didn't like the way he was depicted. He tried to stop the government from giving us cooperation.

CHARTOFF: A month before we began, NASA withdrew permission for us to shoot at their facilities. I flew to Washington and argued that pulling our access wasn't fair—we're American citizens. The next morning I called them and they said, "We have no right to deprive you of use of our facilities, you've got them."

CALEB DESCHANEL: When we were at Edwards Air Force Base, we really had the run of the place. We'd be right along the runways. Some pilots would get ticked off because we were too close. But Yeager was with us a lot of the time. One pilot landed and was like, "Who the hell are you?! What's going on?! Who's in charge?!" Finally Chuck Yeager turns around, and the guy's face suddenly fell. He said, "Oh, General, I'm really sorry, I didn't realize that you were with these guys." You could do anything you wanted at Edwards as long as Yeager was around.

SHEARER: Late in the process we were called up to the Bay Area for the shoot on the aircraft carrier.

WARD: The USS *Coral Sea*.[3]

CALEB DESCHANEL: They gave us two lectures. Both of them had to do with not getting killed. These huge cables catch the planes when they land. Every once in a while they go *snap*. If you're there when they snap, they just cut you in half.

GOLDBLUM: Of course, I feel at home at sea because I was a whaler before I became an actor. No, that's not true. I'd hardly been at sea. I'm not really seafaring.

SHEARER: We were going to be going out through the Golden Gate and spending the night. Jeff and I are taken down to where we're going to be bunking. It's cramped. There's water on the floor. We looked at each other and said, "Gee, I don't know about this."

PHILIP KAUFMAN: Harry and Jeff were a little grumpy. So Peter and I took them back to my apartment.

SHEARER: The script had me throwing up on the aircraft carrier. I had real qualms about it. I thought, man, it's going to look so fake. I didn't want to be busted with that: Yeah, the movie was great, but man, Shearer throwing up, ooh.

CALEB DESCHANEL: We sent Dennis Quaid up with a test pilot. He had a Nagra recorder in the cockpit. Phil leans over to the pilot and says, "Give him an exciting ride." So they go up and come back down 20 minutes later, and Dennis is green. The sound guy goes in to get his Nagra, and Dennis had thrown up all over it. In the dailies, you see Dennis smiling, and then the pilot starts doing barrel rolls, and Dennis disappears from the frame. We asked Dennis about it and he said, "Oh, I had my script on the floor and I was just checking my lines." It was total bullshit.

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[3] The USS *Coral Sea*, a 45,000-ton aircraft carrier, was decommissioned in 1990.

PREVIOUS SPREAD: EVERETT COLLECTION (1-6, 11-12), RON GROVER/MPTV (7-9), US AIR FORCE (10); WARD: GROOMING BY LOUISE MOON. PHOTOGRAPHED AT SHUTTERS ON THE BEACH

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V.

“We Didn’t Fly Those Planes, We Wore Them.”

Yeager’s spirit of daredevilry infected the film and the cast. That, combined with shooting on active military bases, occasionally made for dangerous shooting conditions.

PHILIP KAUFMAN: Tom Wolfe ascribed a voice to Chuck Yeager—a sort of West Virginia drawl—that is the voice of “the right stuff.” Sam didn’t have that. Levon Helm did, and that’s why he’s the narrator of the movie.

CALEB DESCHANEL: Sam Shepard doesn’t fly; he drives everywhere he goes.

SHEPARD: I grew up in the country. A lot of country people don’t like to fly, they don’t like leaving the ground, but I went up with Yeager in a Piper Cub. I figured if I died while flying with the greatest pilot in the world, it would be OK.

> “I WENT UP WITH YEAGER IN A PIPER CUB. I FIGURED IF I DIED WHILE FLYING WITH THE WORLD’S GREATEST PILOT, IT WOULD BE OK.”
>
> SAM SHEPARD

PHILIP KAUFMAN: Yeager was like the unseen father that Sam is always looking for in his plays.

SHEPARD: When I first met Chuck, he had an old Ford pickup. Out there by Edwards it’s very flat, and all the streets are perpendicular to each other; he would get up to about 85 miles an hour with his cruise control, and he would hit these intersections without touching the brake. Every once in a while you’d see a car coming from a distance and it was heading right where you were heading, but Chuck would not put the brake on. He would just keep going.

BARBARA HERSHEY (GLENNIS YEAGER): Chuck was so warm and incredibly generous. He even started calling me Glennis, which really meant a lot to me. One of the terrible things about the poor wives of the test pilots was that, when they said good-bye to their husbands in the morning, they didn’t know if they’d see them again that night.[4] I would look at photos of these women and they all looked like they’d been snowed in for the winter.

YEAGER: Barbara Hershey was the spittin’ image of Glennis.

SHEPARD: I asked Chuck what it was like to be an ace pilot, and he said, “Well, by the time I was 12 years old, I’d already killed 26 black bears.” He had no fear.

HERSHEY: Chuck said, “We didn’t fly those planes, we wore them.”

TOM WOLFE (AUTHOR): Yeager is the same wherever you put him: at a card table, at the edge of space, or at a podium. He’s just Chuck Yeager. He’s a totally confident man.

CALEB DESCHANEL: I went up in an F-100, an old two-seater jet, with a test pilot for Lockheed. There were times we would pull out of a dive and I’d actually lose my vision. Everything became sort of a dark reddish brown and then I’d go blind.

PHILIP KAUFMAN: We were shooting at Van Nuys and somehow Caleb and I found ourselves sitting with Dennis in a little airplane. Suddenly we noticed Dennis was talking to the control tower and the plane was moving! We said, “What the fuck’s going on here!?” Dennis had learned how to fly during the shoot, and suddenly he takes off. Caleb and I were terrified.

KIRKLAND: I think it’s the single most dangerous filming environment I’ve ever been in.

CALEB DESCHANEL: We put a camera in a wingtip gas tank on an F-104 to get some shots. And then other shots we did with a guy named Art Scholl, a really wonderful pilot who could do incredible maneuvers. Unfortunately, he died doing footage on *Top Gun*.

SHEPARD: We didn’t have many accidents. One guy unfortunately got killed doing the parachute drop. The chute just didn’t open.

PHILIP KAUFMAN: We didn’t use any of those shots. We were all stunned. It was so connected with the theme of the movie, how dangerous all of this stuff was.

VI.

“You Can’t Get That Many Great Guys Together and Not Have a Little Bit of Fun.”

As shooting rolled on, the actors inherited the astronauts’ spirit of swaggering camaraderie.

HARRIS: Tosca Café, a bar in North Beach, was the main hangout. We made some history there.

MARY JO DESCHANEL: The owner, Jeanette, was a friend of Phil’s. He wanted it to be kind of like Pancho’s, the bar in the movie where the test pilots hang out.

SHEPARD: After shooting all

[4] “She’d throw things,” Yeager told Hershey of his wife, “but she wouldn’t get emotional.”

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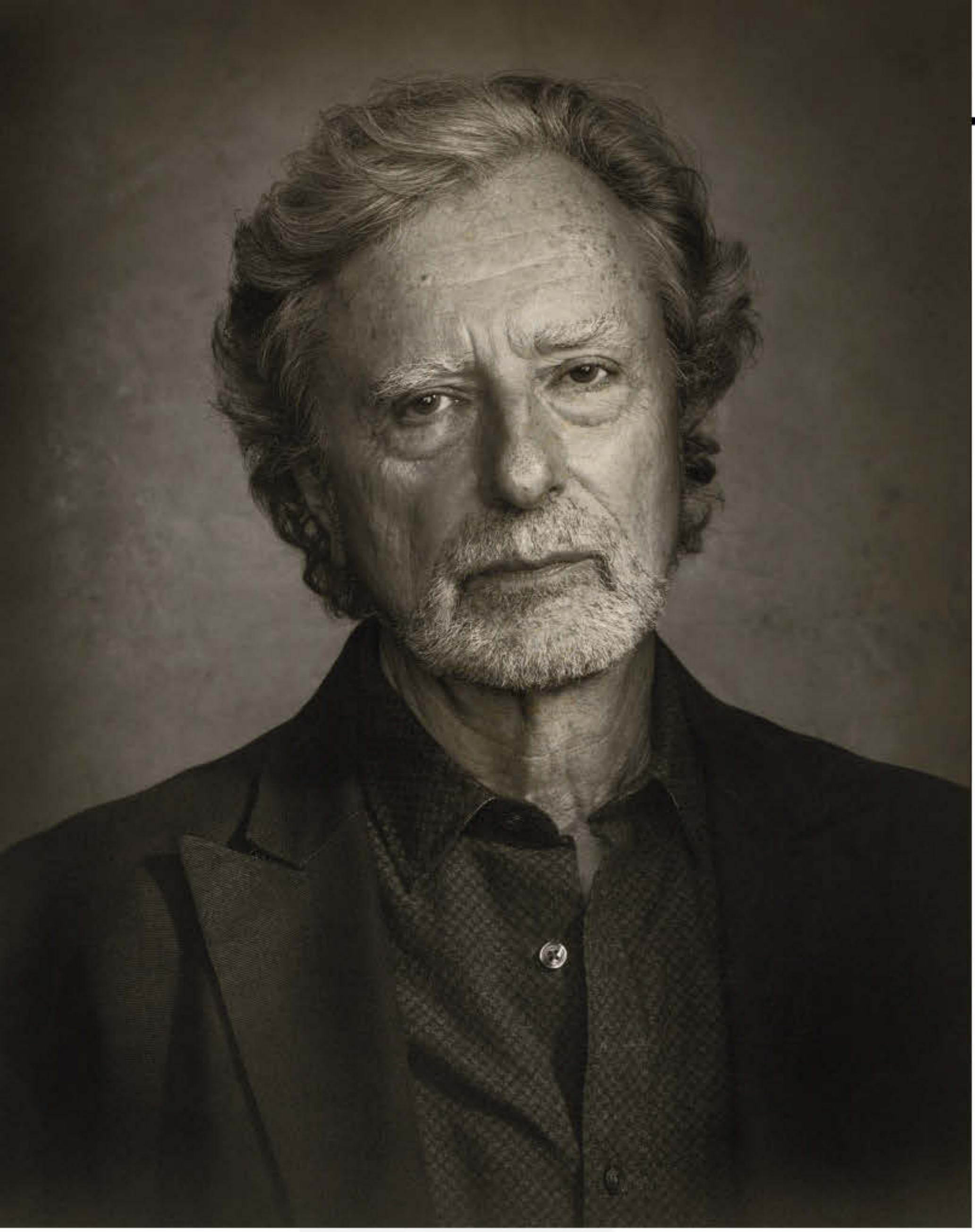

Director Philip Kaufman: "I really wanted the film to be sold as about 'the right stuff': men in leather jackets, the cowboy thing."

DAN WINTERS

day out in the desert, I'd play pool with Yeager at Tosca.

PHILIP KAUFMAN: Scott Glenn looked like Alan Shepard; he had that flinty, tough-as-nails, competitive attitude. All the actors carried that attitude with them off camera, all through the movie. They lived in character for a long time.

SHEPARD: Eddie and me were big buddies and we liked liquor a little bit more than we should have. And yeah, we got into some fights in that bar.

HARRIS: Lance Henriksen and I were at the Holiday Inn at Fisherman's Wharf. I had a couple beers and I got on a luggage cart and was scootering it out through the front doors. It went off a curb and I went flying, smacked my face on the ground. I had a major black eye—and had to do a scene.

CALEB DESCHANEL: Ed shows up, and I'm like, what am I going to do? The set was built, and I actually had to have them reverse it so I could have the light coming in from another side so you couldn't see his black eye.

HARRIS: Phil suggested maybe I was drinking too much. I think he was probably right.

SHEPARD: You can't get that many great guys together and not have a little bit of fun.

VII.

"Can a Movie Help Make a President?"

The film's October 1983 release happened to coincide with the presidential candidacy of John Glenn, which presented both an opportunity and a challenge.

PHILIP KAUFMAN: I was very fussy about nobody seeing the movie before it premiered at the Kennedy Center in Washington, DC. Reagan got a copy, secretly—maybe he'd seen *Newsweek*.

HARRIS: There was a big picture of me on the cover: "Can a Movie Help Make a President?" It gave a much different impression of what the movie was about.

PHILIP KAUFMAN: I really wanted the film to be sold as about "the right stuff": men in leather jackets, the cowboy thing. The movie should have been marketed as tougher and more mysterious than that magazine cover.

PETER KAUFMAN: With the help of Dolby technicians, we helped create new standards for the use of Dolby sound.

PHILIP KAUFMAN: Kissinger was sitting at the premiere. I said, "I want to see chins vibrating." I went up in the projection room and said, "Louder." The whole fucking theater was shaking.

CALEB DESCHANEL: Phil wanted to pass out vomit bags at the screenings.

LADD: The film is a classic, but I think of it as a box office flop at the same time.

WINKLER: We won four Oscars.[5] But we thought it would be a really, really big moneymaker. It wasn't.

LUCAS: The pivotal movie before *The Right Stuff* was *2001*; that was like floating down a river. *The Right Stuff* had more of a documentary edge. It's seamless—the standard until *Gravity*.

SHEARER: It's a stunning piece of work.

MARK KELLY (ASTRONAUT): I've seen the movie a dozen times. It got me excited about the space program—I ended up flying four times on the space shuttle.

PHILIP KAUFMAN: The last line an actor says is Dennis Quaid's. He's going up after he's launched, total grace under pressure. "The sun is coming through the window now," he says. "Oh Lord, what a heavenly light." W

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[5] Best film editing, best sound, best sound effects editing, and best music (original score).

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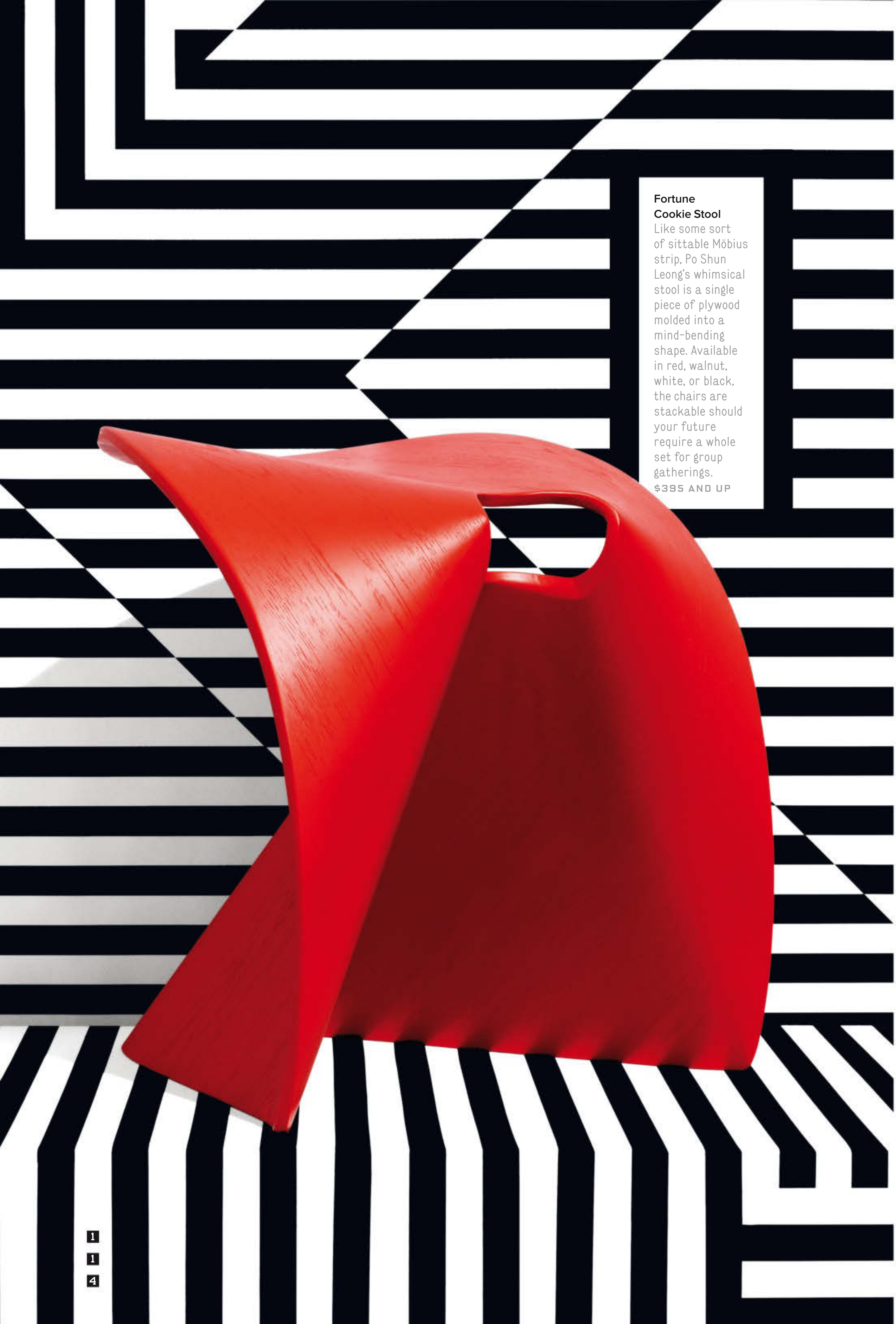

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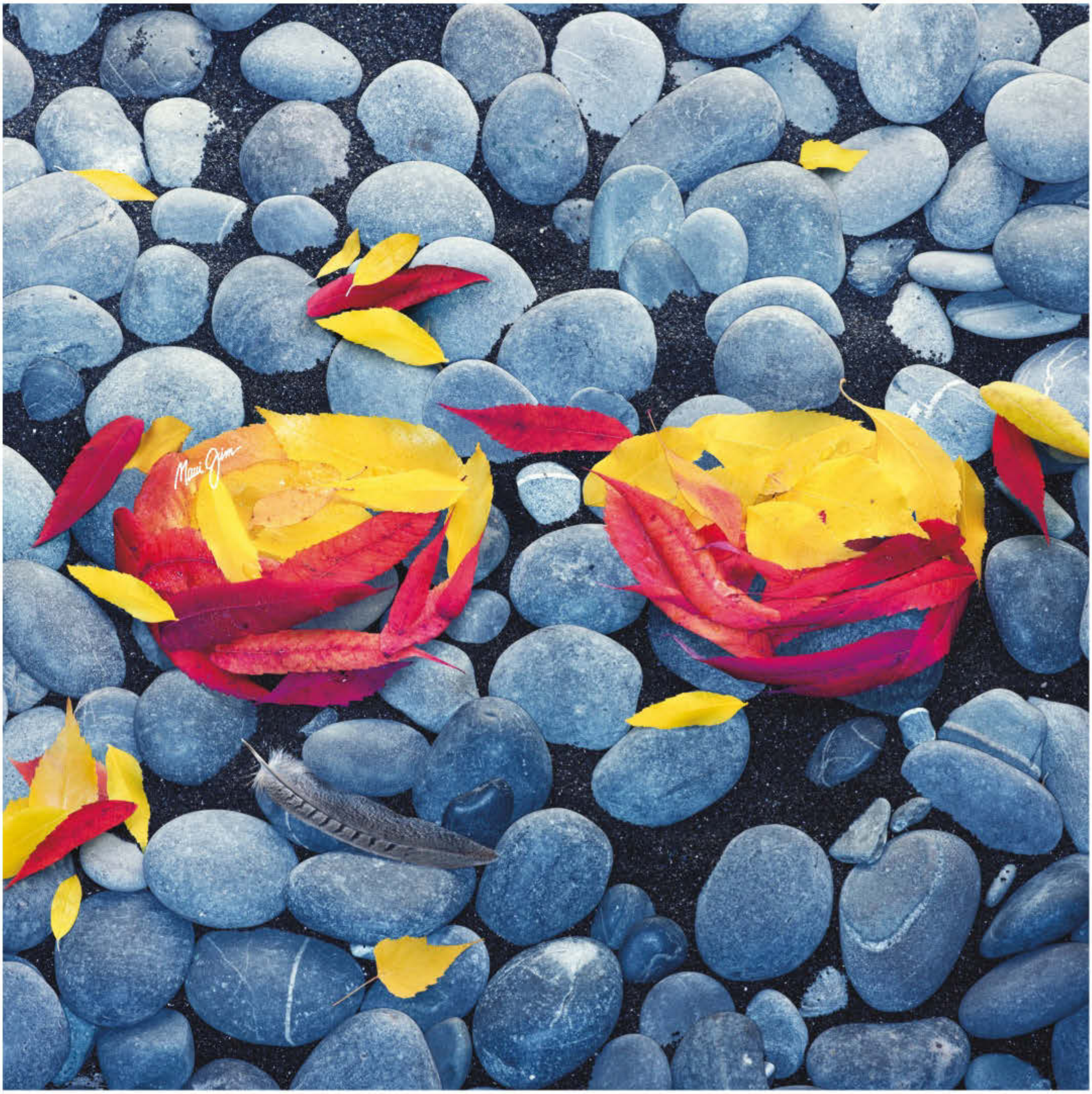

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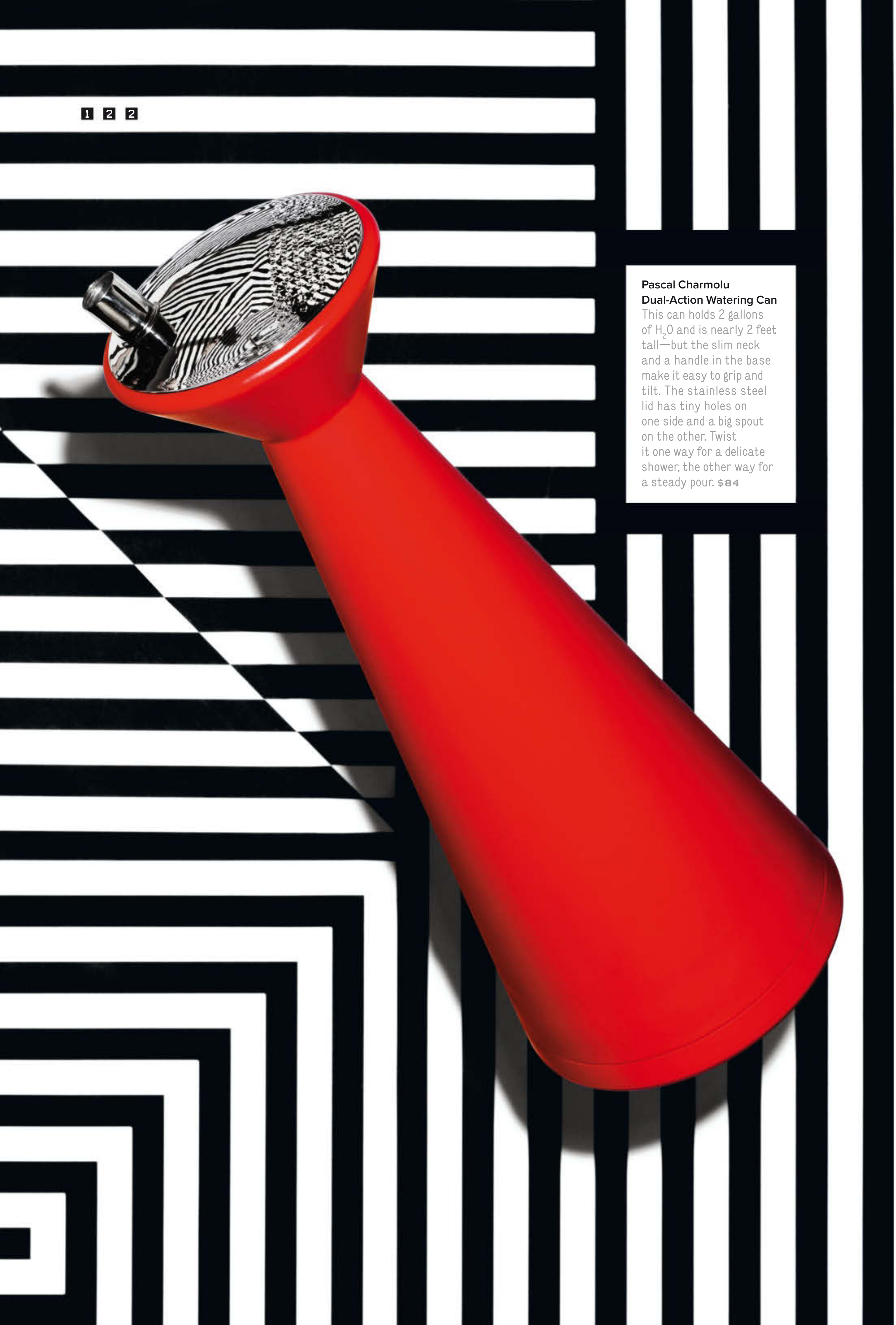

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Sowden SoftBrew Coffeemaker
Coffee experts evaluate roasts by cupping—mixing grounds in a cup and then tasting from a spoon. This pot replicates that method, immersing the grounds, then straining them with a superfine 150-micron filter. You get the robust flavor, no spoon required. $60

BioLite KettleCharge
A must-have for connected campers, this compact kettle has a thermoelectric generator in the base. Boiling water inside produces 10 watts of electricity that you can use to boost your mobile. Fifteen minutes over the flame earn you up to five hours of talk time. $150

Filson Dog Travel Mat
Dogs love outdoor antics. They also love veg mode. This portable hound-chillaxer has a foam core and a water-resistant underside for plush, dry comfort. It rolls up like a burrito and has handles, making it easy to carry. Everybody wins—especially your li'l Boo-Bear. $135

A. Lange & Söhne Saxonia Automatic
When watch nerds argue about who makes the best timepieces in the world, Lange is always in the conversation. The Saxonia is a good example of why. Inside the pink-gold case is a hand-built, self-winding movement that's only 3.7 mm tall. $25,800

Chaco Holbuck Waterproof Boot
Whether you just like a good day hike or your buddies call you Trail Mix, strap Chaco's new boots to your hooves. Water-resistant and made from a mix of rugged materials, their cushy footbed will have you trekkin' without a lengthy break-in period. $150

Polaroid SLR 690
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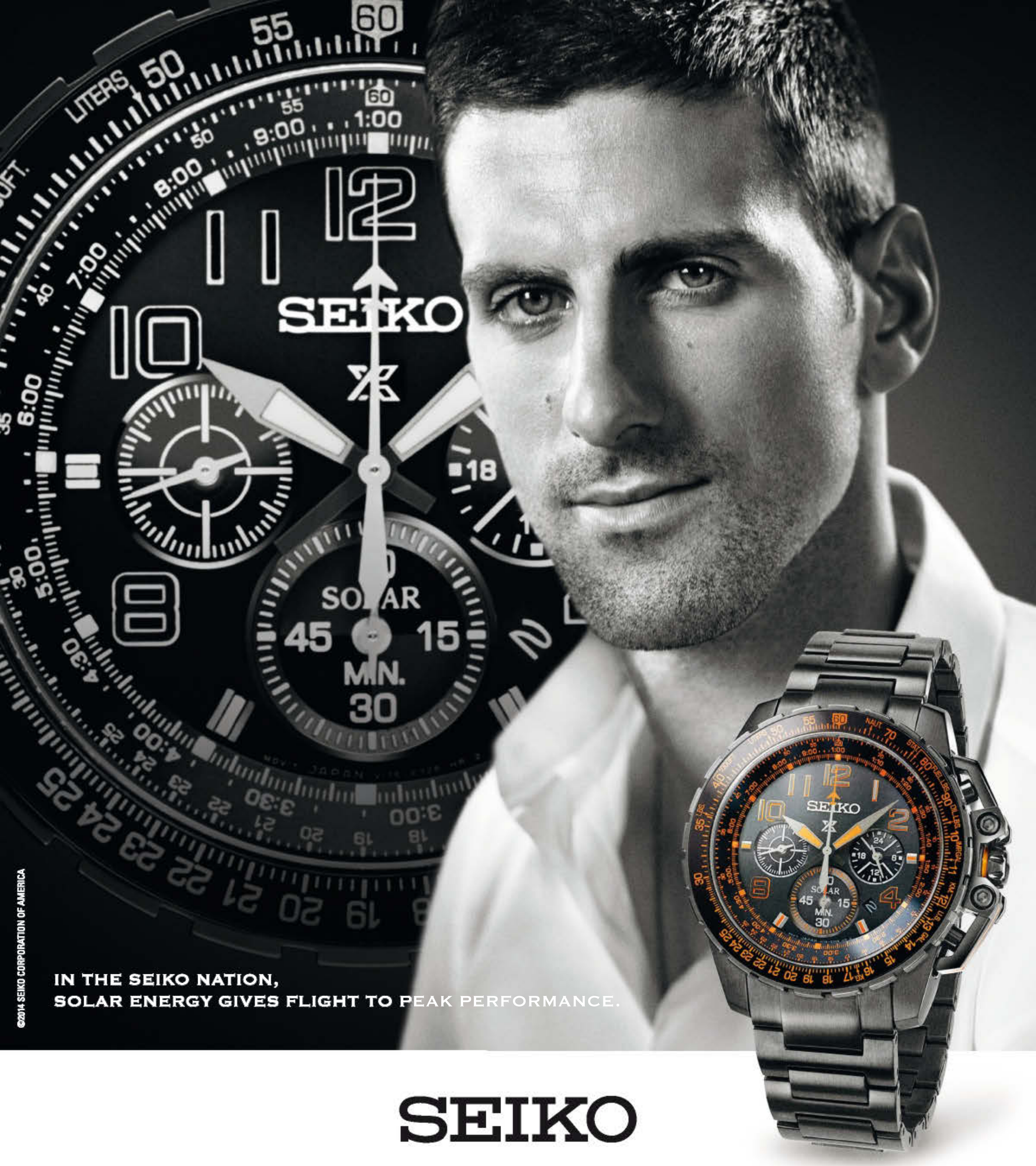
BRYAN EDWARDS; POLAROID: STEPHANIE GONOT



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Killspencer Boxing Speed Bag
A good punching bag should be built to take a beating. This gorgeous jet-black speed bag is made of durable, triple-stitched leather panels, and it's finished with oversize brass rivets. Available with or without its beefy steel swivel, you can hang it in your existing gym or use it to start a new one. **$225**

Harman AKG K545 Headphones
Some headphones only sound good plugged into an amp in your home. But these over-the-ear cans are more versatile. You get two cables: one for Apple gear, another for everything else. Soft ear pads keep city noise out, and the big 50-mm drivers keep the grooves throbbing. **$250**

Hoka One One Mafate Speed Shoes
Barefoot-inspired running shoes aren't for everyone—new research shows extra cushioning is the better bet for most of us. The Mafate Speeds are engineered to protect. The rugged, off-road-ready sole provides cleatlike traction, and the EVA midsole has mountains of shock absorption. **$170**

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5 NOTE TO SELF
LOGITECH KEYS-TO-GO

You never know when you'll have something important to say, remember or write. The Logitech Keys-To-Go—an ultra-portable Bluetooth keyboard—can tag along and is always ready for when inspiration strikes. Its thin and light design makes it easy to take anywhere, and thanks to the water-repellent and wipeable FabricSkin, it can weather any situation.

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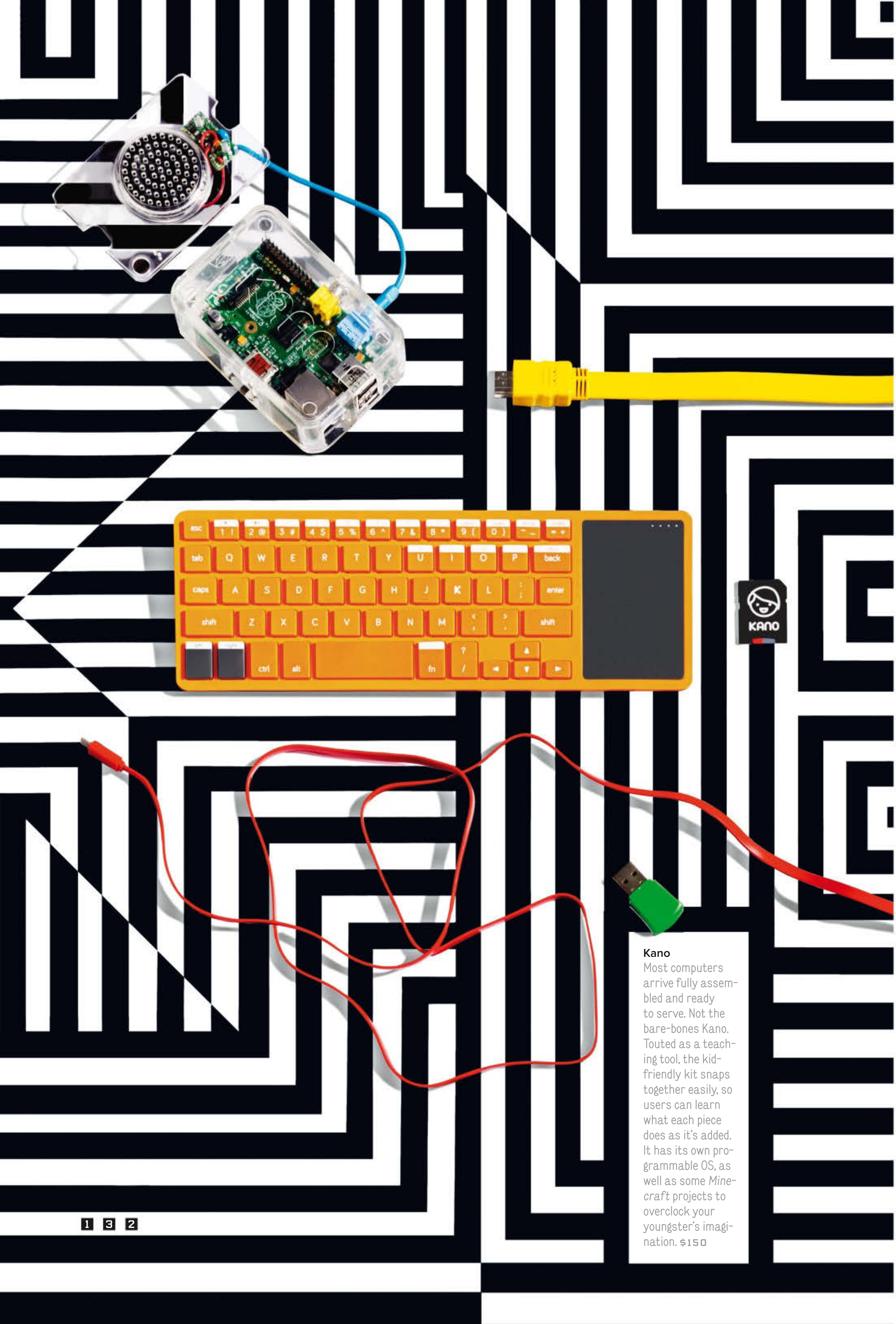

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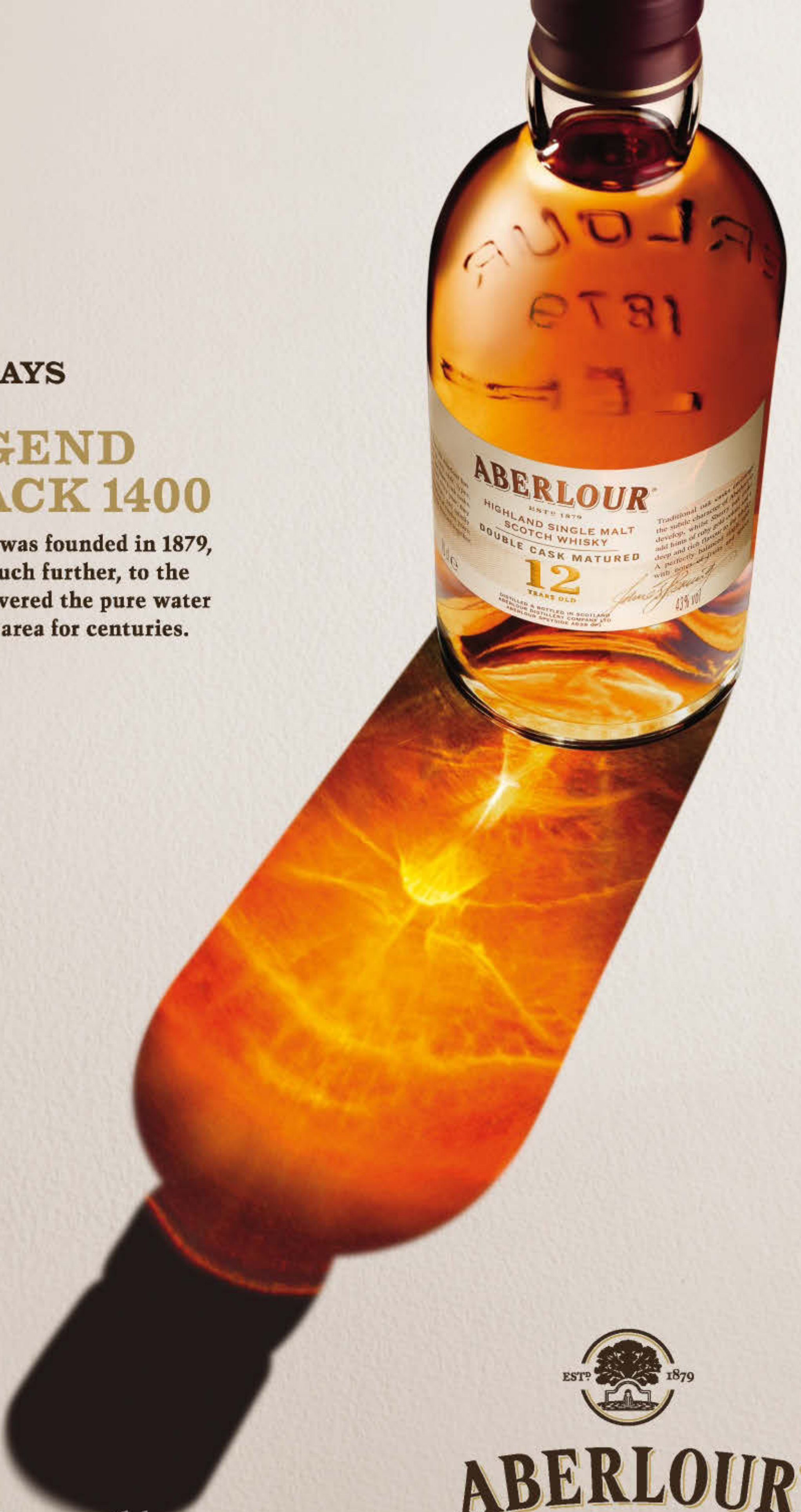

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Sage Accel Rod
Fly-fishing rods can be described by "action," the speed with which they respond. Some anglers like fast action, others like it slow. Sage's Accel is in between: quick enough to set a hook but not so rapid that we spazzes will pluck the fly from the fish's mouth. $595

Bloom Blanket
The star-shaped protuberances are inspired by origami. Its overlapping designs form pointy prisms of wool-cashmere softness, and the blanket's odd topography stays intact without filling. It doesn't fold easily, but that's OK—it looks best spread out. $300

Moment Lenses
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Sonos Play:1
These tiny speakers have a technological advantage over other wireless audio systems: They don't interfere with your home Wi-Fi. And thanks to an update to Sonos' product line, you no longer need any special hardware to set them up. $199

McIntosh Headphone Amp
It's fun watching the VU meters on this headphone amp do their decibel dance, but that's nothing compared to hearing the amazing clarity the hand-wound components and digital audio converter inject into your music. $4,500

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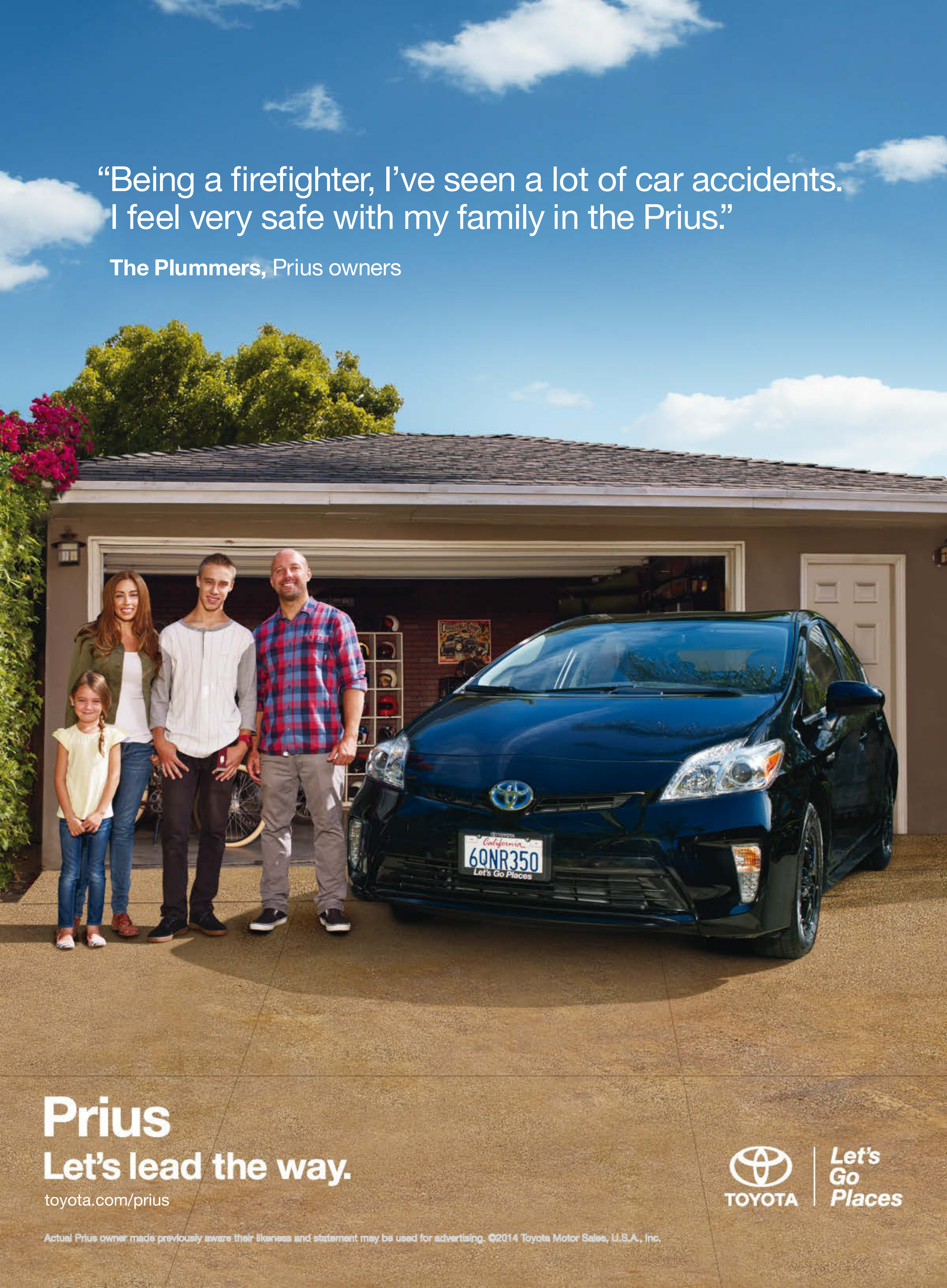

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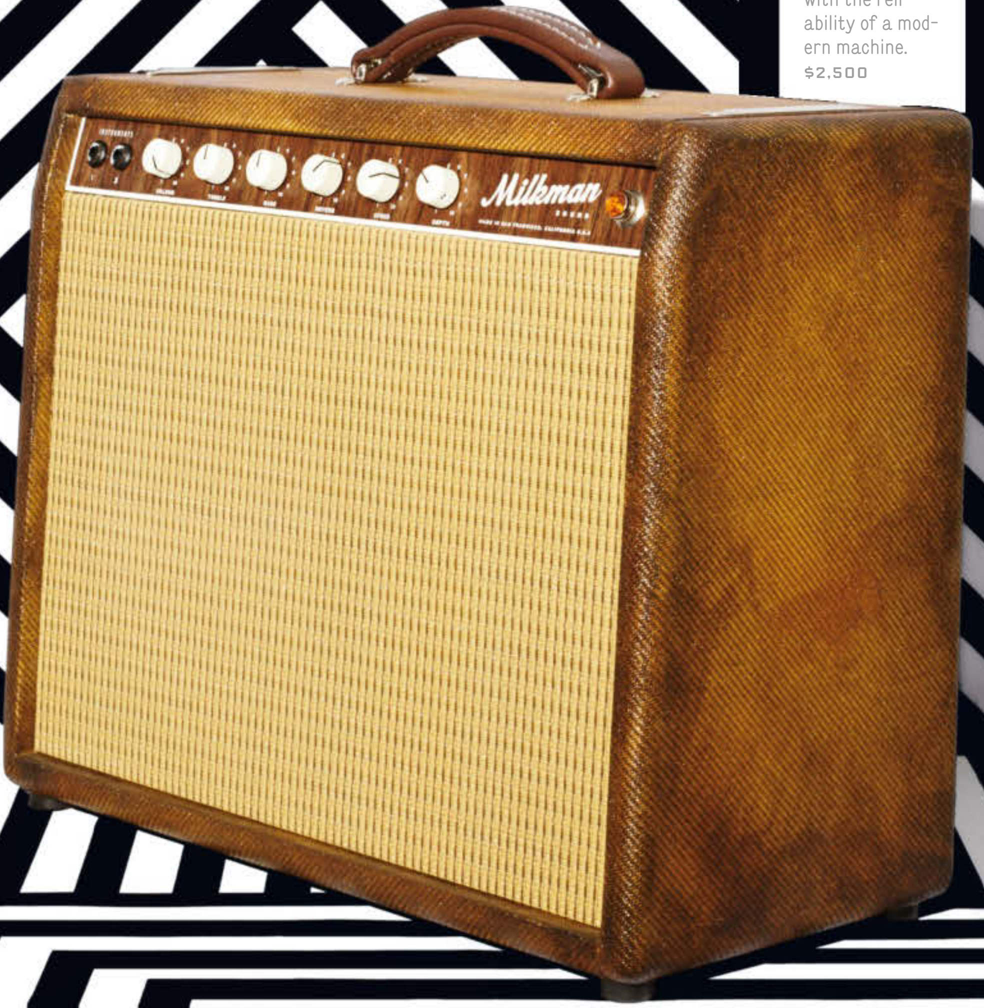

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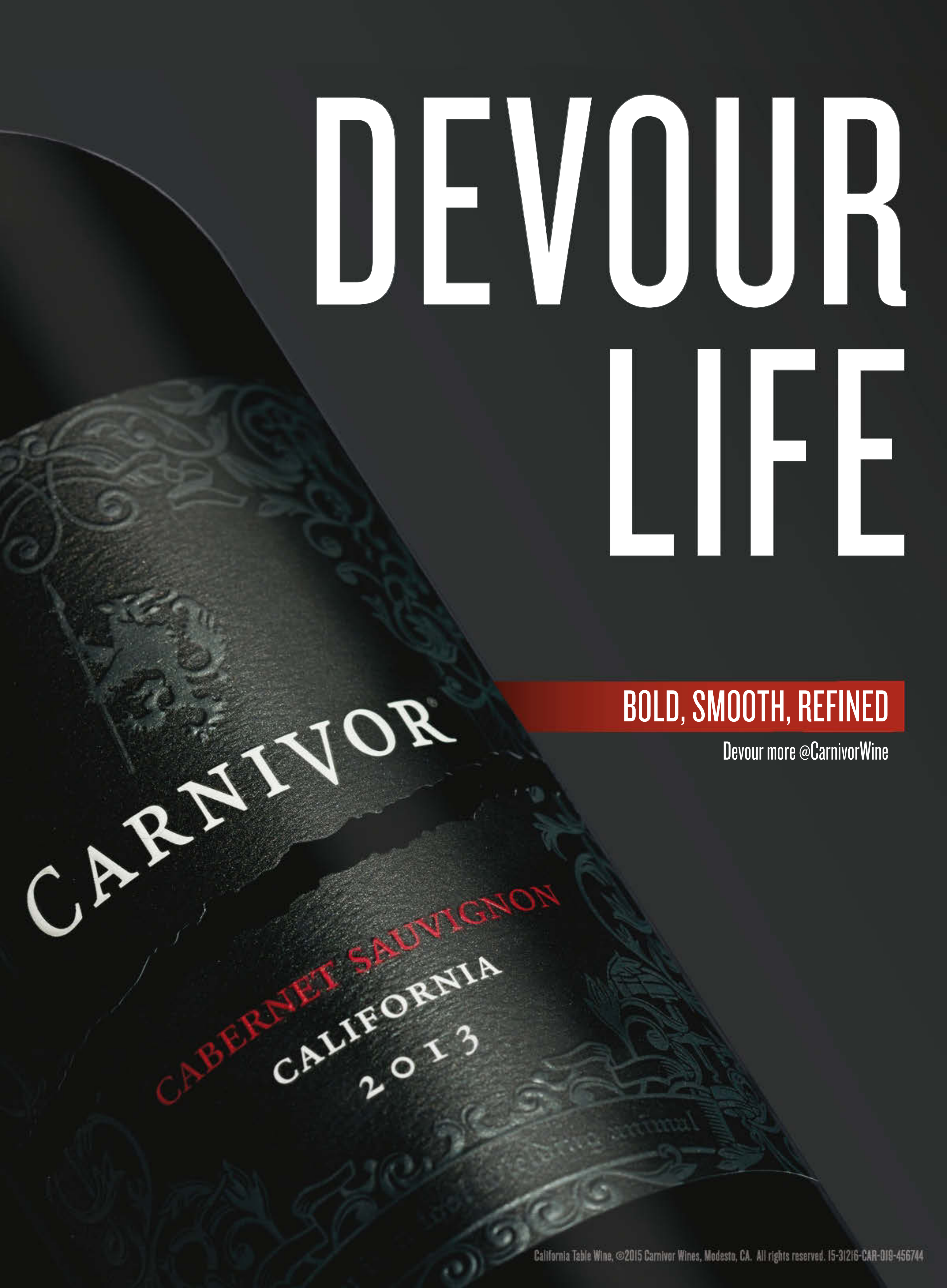

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AT LAST TO SET SAIL
FOR THE STARS."

CARL SAGAN

THIRD DIMENSION: SPACE

DISPATCHES FROM THE FRONTIERS OF EARTH, THE SOLAR SYSTEM, AND BEYOND.

144

"WE BEGAN AS
WANDERERS, AND WE
ARE WANDERERS
STILL. WE HAVE LINGERED
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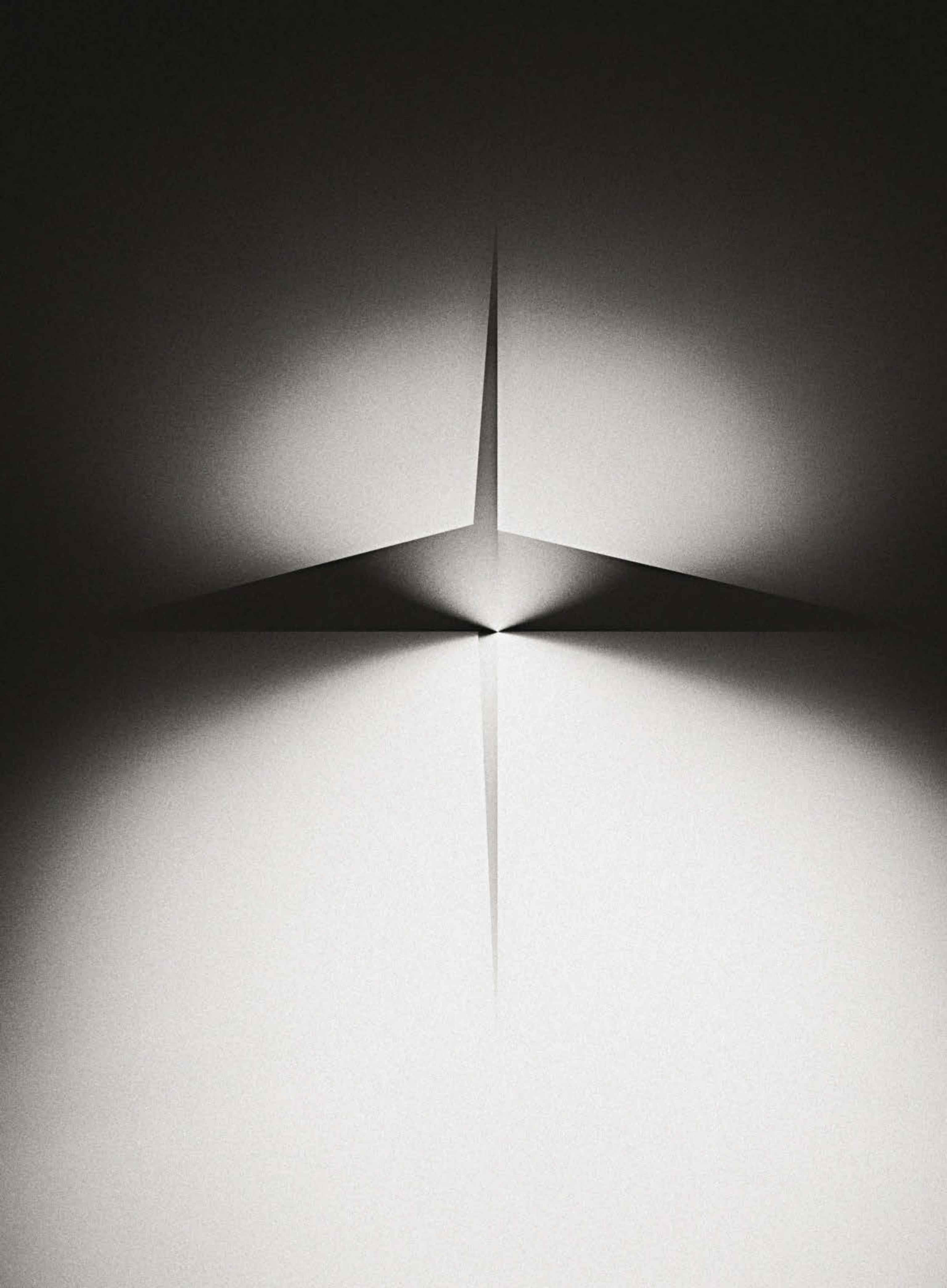


The Other Stuff

AN ASTRONAUT REVEALS
WHAT LIFE IN SPACE IS REALLY LIKE.

MARSHA IVINS

AS TOLD TO
CAITLIN ROPER

DAN WINTERS

T

THERE'S NO WAY to anticipate the emotional impact of leaving your home planet. You look down at Earth and realize: You're not on it. It's breathtaking. It's surreal. It's a "we're not in Kansas anymore, Toto" kind of feeling. But I've spent a total of 55 days in space, over the course of five missions for NASA, and I've learned that being out there isn't just a series of breathtaking moments. It's a mix of the transcendently magical and the deeply prosaic. It can be crowded, noisy, and occasionally uncomfortable. Space travel—at least the way we do it today—isn't glamorous. But you can't beat the view!

Everyone imagines that when you're sitting on the launchpad atop 7 million pounds of explosive rocket fuel, you're nervous and worried; but the truth is, there isn't much to do for those two hours after you climb into the shuttle. Many astronauts just take a nap. You're strapped in like a sack of potatoes while the system goes through thousands of prelaunch checks. Occasionally you have to wake up and say "Roger" or "Loud and clear." But the launch itself is a whole other thing—from the pad to orbit in 8.5 minutes, accelerating the entire time until you reach the orbital velocity of 17,500 mph. *That* is a ride.

It turns out that once you're actually in orbit, zero-g has some upsides. Without gravity, bodily fluids move toward your head. It's a great face-lift. Your stomach gets flat. You feel long, because you grow an inch or two. (I thought, "Oh cool, I'll be tall," but of course everybody else was taller too.)

But zero-g also has some disadvantages. As that fluid shifts north, you get an enormous headache. Your body compensates and loses about a liter of fluid in the first couple of days—you essentially pee the headache away. And a lot of people get nauseated. The way to feel better is to "lose up," to convince your visual system that "up" is wherever you point your head and "down" is where your feet are. When you can do that, and go headfirst or earlobe-first wherever you want, then you're getting adapted to zero-g. On each flight this adaptation happens more quickly—your body remembers having been in space. But it can take a few days before your stomach finally settles down and says, "OK, what's for lunch?"

I didn't eat much on any of my flights. I don't have a big appetite even on Earth, but between the lack of gravity and the shifting fluids, things can taste different in space. I'd bring great chocolate with me and it would taste like wax—it was very disappointing. But you don't go to space for the gourmet dining. There's no way to cook, on the shuttle or on the ISS. Space food is already cooked and then either freeze-dried and vacuum-packed—so you add water and put it in the oven to warm up—or it's thermostabilized, like a military MRE. With no refrigerator on board, fresh food won't keep. So on the shuttle we'd have to eat anything fresh—usually fruit like apples, oranges, and grapefruit—early in the mission.

One of the strangest experiences in space is one of the simplest on Earth: sleeping. On the shuttle, you strap your sleeping bag to the wall or the ceiling or the floor, wherever you want, and you get in. It's like camping. The bag has armholes, so you stick your arms through, reaching outside the bag to zip it up. You tighten the Velcro straps around you to make you feel like you're tucked in. Then you strap your head to the pillow—a block of foam—with

Astronaut Marsha Ivins on board the space shuttle *Atlantis* in 2001, her fifth mission.

NASA. HAIR AND MAKE-UP BY TAMARA BROWN/ARTIST UNTIED.

DAN WINTERS

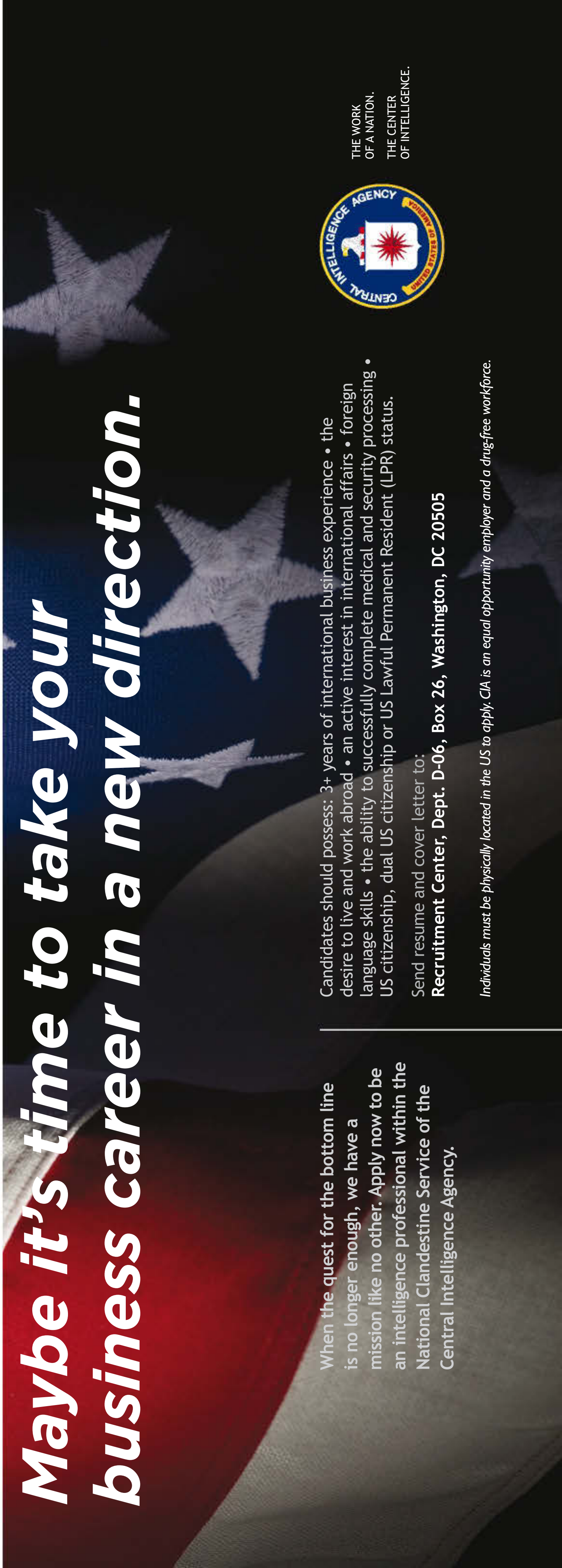
another Velcro strap, to allow your neck to relax. If you don't tuck your arms into the bag, they drift out in front of you. Sometimes you wake up in the morning to see an arm floating in front of your face and think, "Whoa! What is that?" until you realize it's yours.

On most of my flights, I slept in the airlock, in the middeck of the shuttle. Nobody worked in there when we weren't doing an EVA (extra-vehicular activity), so it was like my own private bedroom. The downside? It was also the coldest part of the shuttle by about 20 degrees. I would tuck my arms into the bag and wear four layers of clothes; sometimes I'd warm up a package of food in the oven and throw it in my sleeping bag like a hot-water bottle. On the last two nights of my final flight, I slept on the flight deck, my sleeping bag strapped beneath the overhead windows. The position of the shuttle put Earth in those windows, so when I woke up the whole world was out there in front of me—in that moment, just for me alone.

The most amazing thing about my spaceflights was how relaxing they were. New astronauts get so worried about fulfilling their duties that they sometimes get hours or days into a mission before stopping to watch the sun rise, even though it happens 16 times a day on orbit. Shuttle flights were always busy—experiments, daily maintenance, EVAs, robotic operations. It was incredibly hard work, stressful in its own way, and scary—if you screwed up, you screwed up with people all over the world watching. But at the same time I found it all very relaxing. When you travel on Earth, you're almost never out of touch. Anyone can reach you if they need to. But going to space, you are *really* out of reach. You have comm with the ground and email, sure, but there's not much you can do about those everyday worries: Did I pay the bills? Did I feed the dog? I felt like everyday things just stopped at the edge of the atmosphere. I was totally liberated from Earth. But all those earthly concerns reattached as soon as we reentered. By the time I landed, my brain was mapping out a to-do list.

I never got sick going to space, but I never felt great coming home. When you return, your inner ear—which keeps you balanced on Earth and which has been essentially turned off for the duration of your trip—feels a little gravity and becomes unbelievably sensitive. Your balance is off and you have to relearn how to move in a gravity field. If I turned my head, I would fall over. Muscles you haven't used in weeks have to reengage to help you do everyday stuff like walk, stand, and hold things. It can take days or weeks to get your Earth legs back.

It was hard, it was exciting, it was scary, it was indescribable. And yes, I'd go back in a heartbeat.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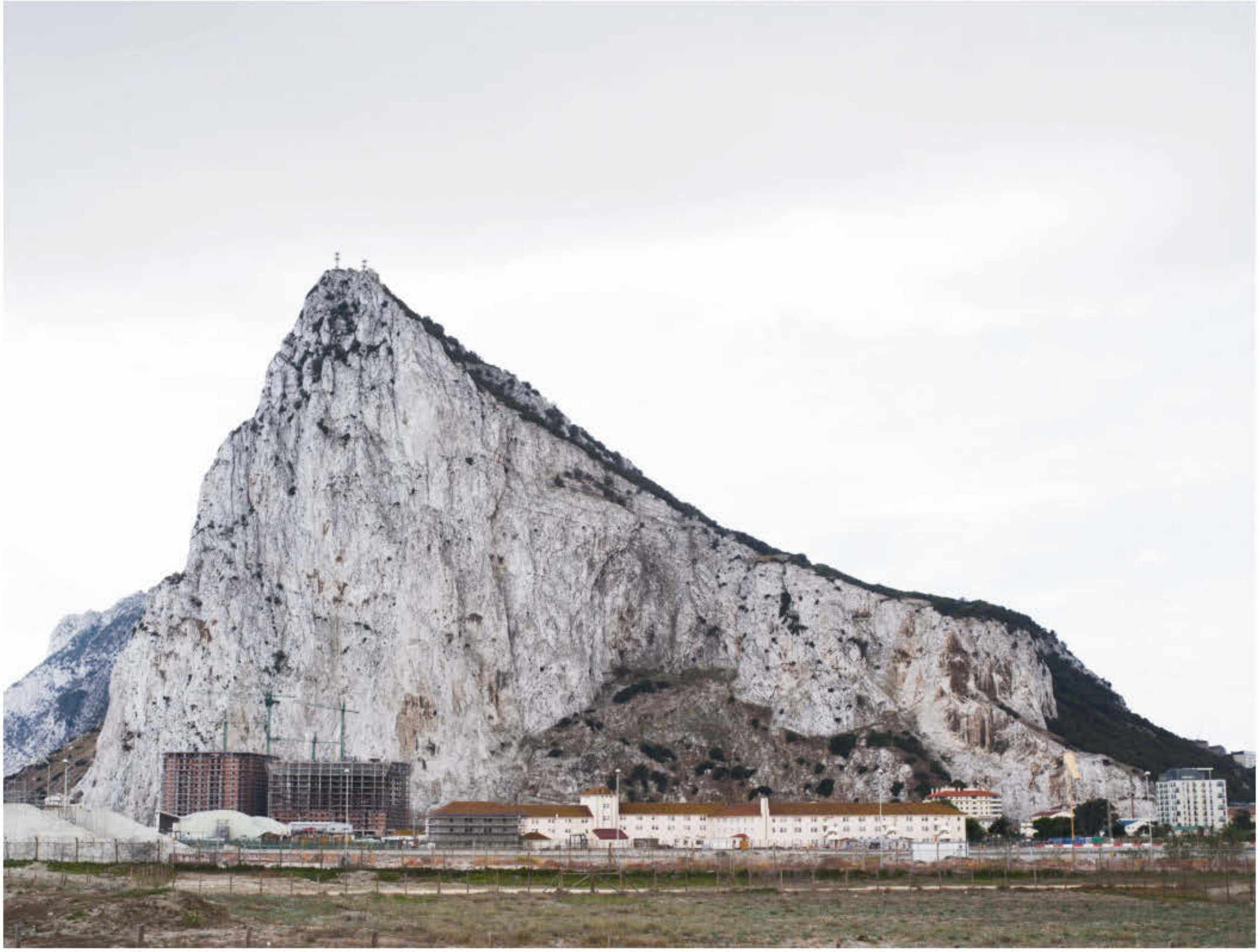

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OF THE EARTH

SCENES FROM OPPOSITE POINTS ON THE GLOBE.

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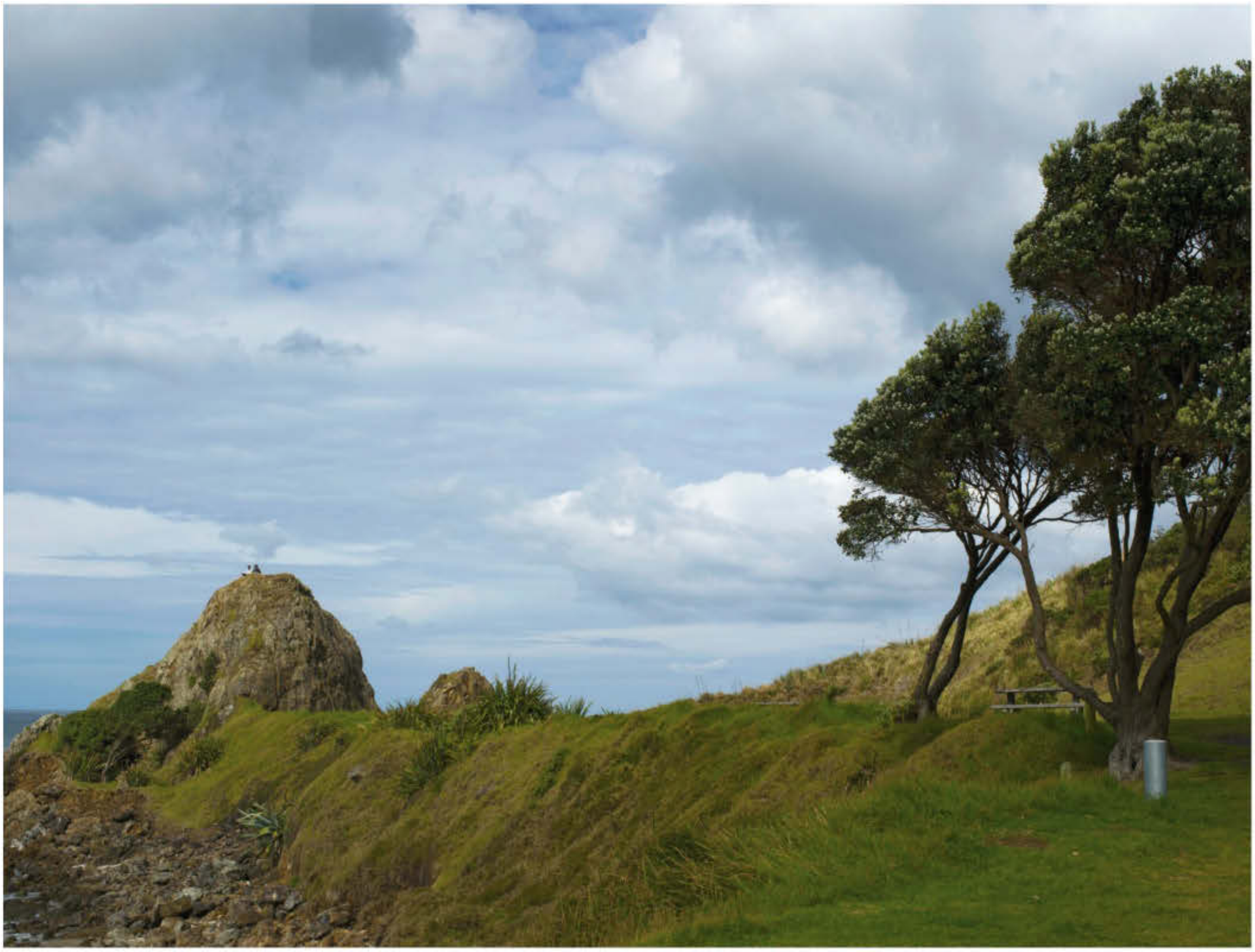
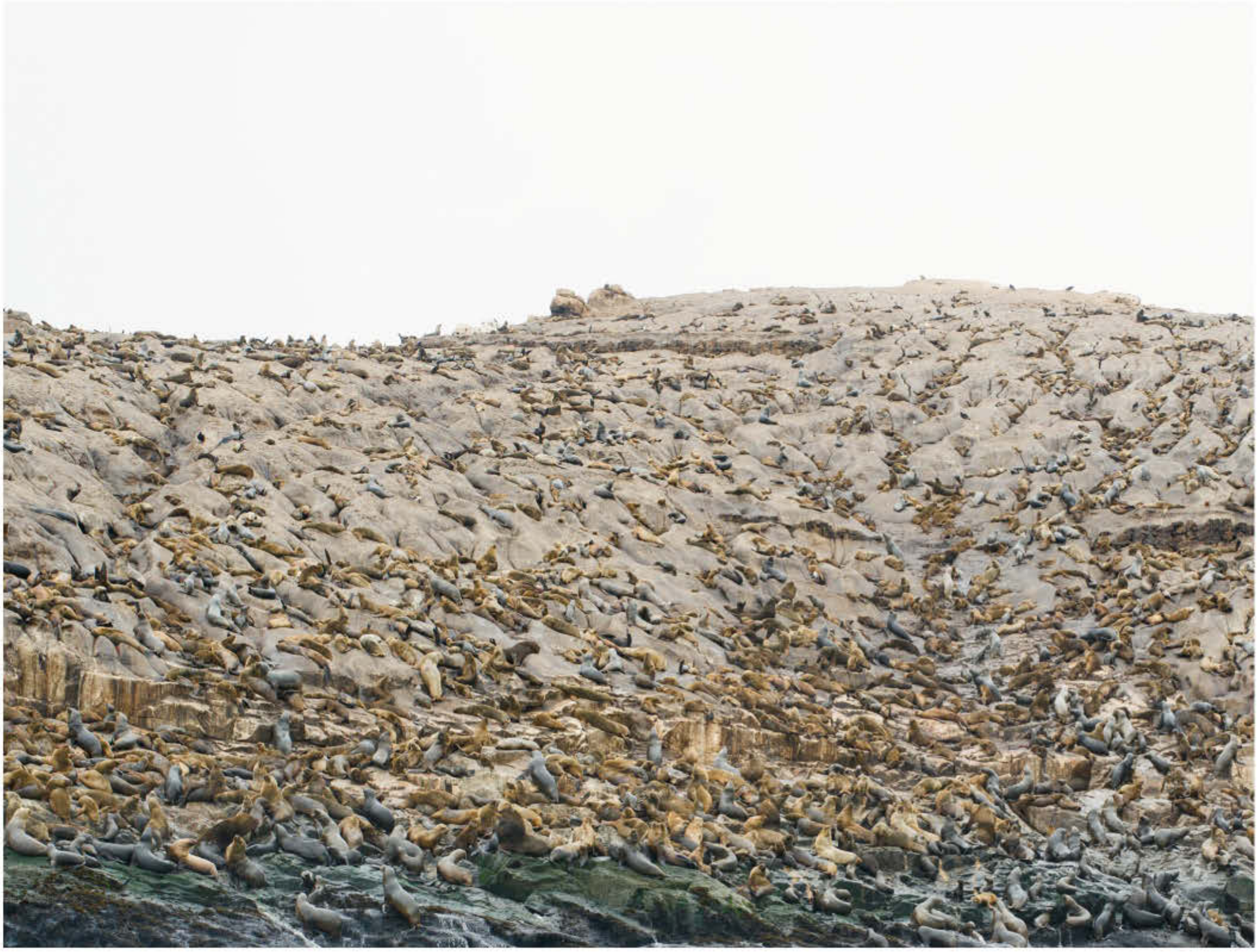
UTA KÖGELSBERGER

TEXT BY ANNA GOLDWATER ALEXANDER

STAND UP. Look at your feet. Now imagine boring a hole straight down. After nearly 8,000 miles that hole would break through to the other side—another hemisphere, another culture, another season, another world. Wherever it ends up, you and the other side are at antipodes, diametrically opposed points on Earth. Say you're standing on the North Island of New Zealand, among the sheep in a grassy paddock. Then you start sinking through the soil, water, crust, mantle, outer core, inner core, *núcleo-externo, capa, corteza, agua, roca. Acaba de llegar al sur de España, denso con ciudades, desfiladeros, y viñedos. O quizás se encuentre paseando por las playas cerca de la Región Callao, Perú—guijarros, el templado océano Pacífico, aire húmedo. Las piedrecitas empiezan a separarse y usted desciende de nuevo a través de arena, agua, corteza, capa, núcleo-externo, núcleo-interno,* แก่นโลกชั้นนอก, เนื้อโลก, เปลือกโลก, น้ำ, ป่า. ภาคใต้ของประเทศไทย, เขียวชอุ่ม, เสือดาว, บ่าง. Ride a wormhole through the center of the earth to new terrain, weather, flora, and fauna. The antipode of the entire continental US is the Indian Ocean. Inundated by it. Stand on the outskirts of Maun, Botswana, *fa pitse ya naga e kgabaganyang tsela ya gago teng. Sekaka se a thibologa o bo o wela. Lentswe, sekgapha, letlapa, mateng a lefatshe,* outer core, mantle, crust, water, sand, lava. Aloha, Mauna Loa.



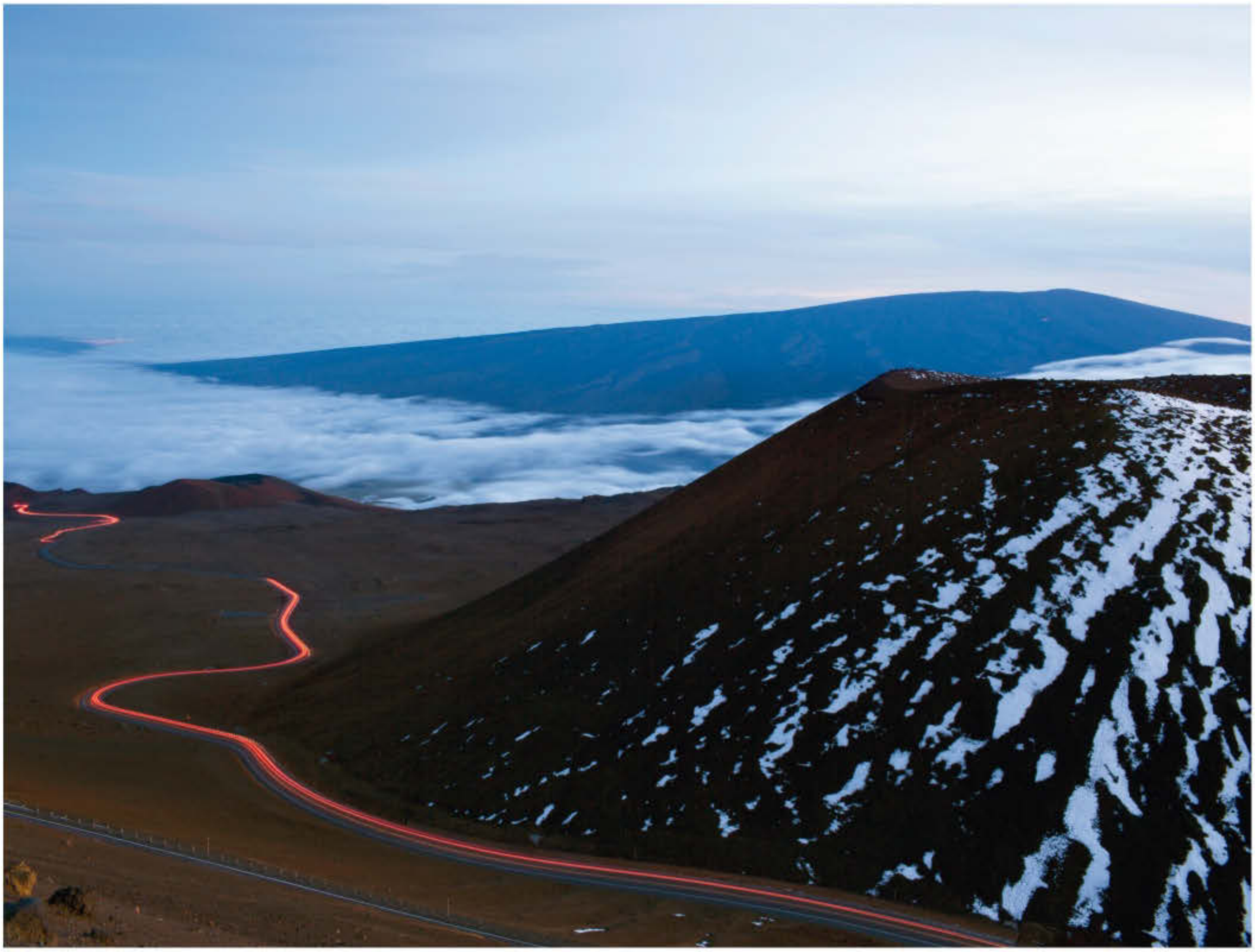
TE ARAI, NEW ZEALAND   LAT: 36° 9' 35.9163" S   LONG: 185° 21' 12.0379" W



LA REGIÓN CALLAO, PERU   LAT: 12° 4' 43.0915" S   LONG: 77° 14' 46.4869" W

SOUTH OF TRAT, THAILAND LAT: 12° 4' 43.0915" N LONG: 102° 45' 13.5131" E

MAUN, BOTSWANA   LAT: 19° 27' 46.2146" S   LONG: 24° 25' 6.5552" E



MAUNA LOA, HAWAII LAT: 19° 27' 46.2146" N LONG: 155° 34' 53.4448" W

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War of

TWO TEAMS OF ASTRONOMERS MAY HAVE FOUND THE FIRST

BY

LEE BILLINGS

the

EARTH-LIKE PLANET IN OUTER SPACE. SO WHO TRULY DISCOVERED GLIESE 667Cc?

Worlds

N**O ONE KNOWS** what the planet Gliese 667Cc looks like. We know that it is about 22 light-years from Earth, a journey of lifetimes upon lifetimes. But no one can say whether it is a world like ours, with oceans and life, cities and single-malt Scotch. Only a hint of a to-and-fro oscillation in the star it orbits, detectable by Earth's most sensitive telescopes and spectrographs, lets astronomers say the planet exists at all. The planet is bigger than our world, perhaps made of rocks instead of gas, and within its star's "habitable zone"—at a Goldilocks distance that ensures enough starlight to make liquid water possible but not so much as to nuke the planet clean. ¶ That's enough to fill the scientists who hunt for worlds outside our own solar system—so-called exoplanets—with wonder. Gliese 667Cc is, if not a sibling to our world, at least a cousin out there amid the stars. No one knows if it is a place we humans could someday live, breathe, and watch triple sunsets. No one knows whether barely imagined natives are right now pointing their most sensitive and far-seeing technology at Earth, wondering the same things. Yet regardless, to be the person who found Gliese 667Cc is to be the person who changes the quest for life beyond our world, to be remembered as long as humans exist to remember—by the light of the sun or a distant, unknown star. ¶ Which is a problem. Because another thing no one knows about Gliese 667Cc is who should get credit for discovering it. ¶ Gliese 667Cc is at the center of an epic controversy in astronomy—a fight over the validity of data, the nature of scientific discovery, and the ever-important question of who got there first.

IN LATE 1995 Swiss astronomer Michel Mayor and his student Didier Queloz found 51 Pegasi b, the first known exoplanet orbiting a sunlike star. It was orbiting far too close to its sun to allow the formation of water, but the discovery made Mayor's European team world famous anyway.

Soon, though, they lost their lead in the planet-hunting race to a pair of American researchers, Geoff Marcy and Paul Butler. The two men had been looking for exoplanets for almost a decade; they bagged their first two worlds a couple of months after Mayor's announcement.

The two teams evolved into fiercely competitive dynasties, fighting to have the most—and most tantalizing—worlds to their names. Their rivalry was good for science; within a decade, each had found on the order of a hundred planets around a wide variety of stars. Soon the hunt narrowed to a bigger prize. The teams went searching for smaller, rocky planets they could crown "Earth-like."

Most planet hunters aren't looking for exoplanets, per se. Those worlds are too small and dim to easily see. They're looking instead for telltale shifts in the light of a star, "wobbles" in its spectral identity caused by the gravitational pull of an unseen orbiting exoplanet. When that force tugs a star toward Earth, the Doppler effect ever so slightly compresses the waves of light it emits, shifting them toward the blue end of the spectrum. When the star moves away from Earth, its waves of starlight stretch to reach us, shifting toward the red. You can't see those shifts with the naked eye. Only a spectrograph can, and the more stable and precise it is, the smaller the wobbles—and planets—you can find.

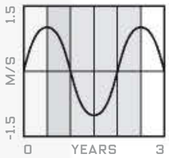
By late 2003 the European team had a very precise instrument, the High Accuracy Radial velocity Planet Searcher, or Harps. Mounted to a 3.6-meter telescope on a mountaintop in Chile, Harps could detect wobbles of less than a meter per second. (Earth moves the sun just a tenth that amount.) The Americans had to make do with an older instrument called the High Resolution Echelle Spectrometer, or Hires—less precise but paired with a more powerful telescope.

As the two teams continued to fight for preeminence, trouble was brewing among the Americans. Marcy, a natural showman as well as a brilliant scientist, regularly appeared on magazine covers, newspaper front pages, and even David Letterman's late-night show. His far more taciturn partner, Butler, preferred the gritty tasks of refining data pipelines and calibration techniques. Having devoted years of their lives to the planet-hunting cause, Butler and another member of the team, Marcy's PhD adviser, Steve Vogt (the mastermind behind Hires), began to feel marginalized and diminished by Marcy's growing fame. The relationships hit a low in 2005, when Marcy split a $1 million award with their archrival Mayor. Marcy credited Butler and Vogt in his acceptance speech and donated most of the money to his home institutions, the University of California and San Francisco State University, but the damage was done. Two years later, the relationship disintegrated. Butler and Vogt formed their own splinter group; Butler and Marcy have barely spoken since.

It was a risky move. Harps and Hires remained the best planet-hunting spectrographs available, and Butler and Vogt now lacked easy access to fresh data from either one. The American dynasty was shattered, and Marcy was forced to find new collaborators. Meanwhile, the ever-expanding European team continued to wring planets from Harps even though Mayor had formally retired in 2007. The search for Earth 2.0, long seen as a struggle between two teams, became a more crowded and open contest.

Then a seeming breakthrough: In the spring of 2007, the Europeans announced that they'd spotted a potentially habitable world, Gliese 581d.[1] It was a blockbuster—a "super-Earth"—on the outer edge of the habitable zone, eight times more massive than our own world.

Three years later, in 2010, Butler and Vogt scored their own big find around the same star—Gliese 581g. It was smack in the center of the habitable zone and only three or four times the bulk of Earth, so idyllic-seeming that Vogt



Stellar wobble
The spectral fluctuations of a star with an exoplanet create a sine wave.

LEE BILLINGS (@leebillings) *wrote* Five Billion Years of Solitude, *published by Current in 2013.*

PREVIOUS SPREAD: ESO/L. CALÇADA

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[1] Astronomer Wilhelm Gliese cataloged hundreds of stars in the 1950s. The lowercase letter marks the order in which astronomers discovered the planets orbiting a star.

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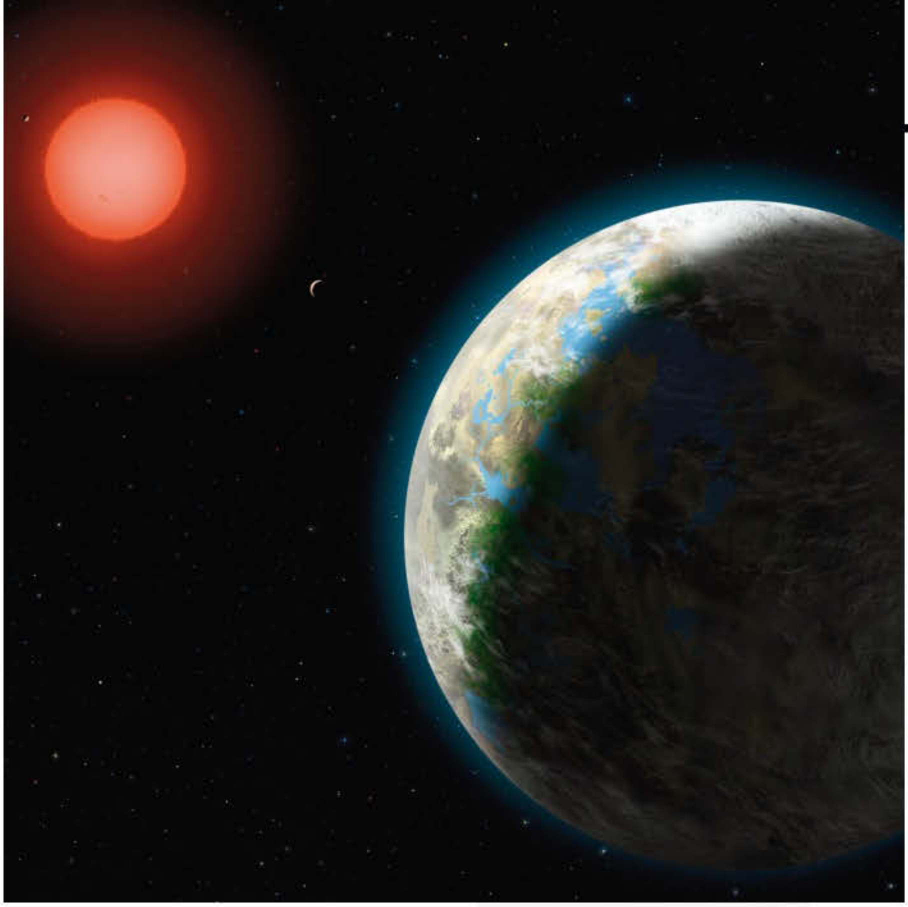

Was Gliese 581g the second Earth-like planet ever discovered? Or would it turn out to be just a ghost?

poetically called it Zarmina's World, after his wife, and said he thought the chances for life there were "100 percent." Butler beamed too, in his own subdued way, saying "the planet is the right distance from the star to have water and the right mass to hold an atmosphere." They had beaten Marcy, laid some claim to the first potentially Earth-like world, and bested their European competitors.

But to a chorus of skeptics, Zarmina's World seemed too good to be true. The European group said the signals the Americans had seen were too weak to be taken seriously. The fight was getting ugly; entire worlds were at stake.

PLOTTED ON a computer screen, a stellar wobble caused by a single planet looks like a sine wave, though real measurements are rarely so clear. A centimeters-per-second wobble in a million-kilometer-wide ball of seething, roiling plasma isn't exactly a bright beacon across light-years. Spotting it takes hundreds to thousands of observations, spanning years, and even then it registers as a fractional offset of a single pixel in a detector. Sometimes a signal in one state-of-the-art spectrograph will fail to manifest in another. Researchers can chase promising blips for years, only to see their planetary dreams evaporate. Finding a stellar wobble caused by a habitable world requires a volatile mix of scientific acumen and slow-simmering personal obsession.

A Spanish astronomer named Guillem Anglada-Escudé certainly meets that description. Now a lecturer at Queen Mary University in London, he began working with the American breakaways Butler (a friend and collaborator) and Vogt not long after they announced Gliese 581g.

Today, Anglada-Escudé's name is on the books next to between 20 and 30 exoplanets, many found by scraping public archives in search of weak, borderline wobbles. The European Southern Observatory, which funds Harps, mandates that the spectrograph's overlords release its data after a proprietary period of a year or two. That gives other researchers access to high-quality observations and potential discoveries that the Harps team might have missed. Scavenging scraps from the European table, it turns out, can be almost as worthwhile as being invited to the meal.

In the summer of 2011, Anglada-Escudé was a 32-year-old postdoc at the end of a fellowship, looking for a steady research position in academia. With Butler's help he had developed alternative analytic techniques that he used to scour public Harps data. In fact, Anglada-Escudé argued that his approach treated planetary data sets more thoroughly and efficiently, harvesting more significant signals from the noise.

One late night that August, he picked a new target: nearly 150 observations of a star called Gliese 667C[2] taken by the Harps team between 2004 and 2008. He sat before his laptop in a darkened room, waiting impatiently as his custom software slowly crunched through possible physically stable configurations of planets within the data.

The first wobble to appear suggested a world in a seven-day orbit—the faster the orbit, the closer to the star the planet must be. A weeklong year is about enough time to get roasted to an inhospitable cinder—and anyway the Harps team had announced that one in 2009, as the planet Gliese 667Cb. But Anglada-Escudé spied what looked suspiciously like structure in the residuals of the stellar sine wave snaking across his screen. He ran his software again and another signal emerged, a strong oscillation with a 91-day period—possibly a planet, possibly a pulsation related to the estimated 105-day rotation period of the star itself.

He decided to try once more before bed, nulling the seven- and 91-day signals. When the final fit was complete, he stared for a long moment at the results on his laptop's glowing screen, then smoked a cigarette to calm his fraying nerves. The software had uncovered what looked to be another planet. But this one had a 28-day orbit, in Gliese 667C's habitable zone. It looked rocky too, because it was just over four times the mass of Earth. This was what came to be known as Gliese 667Cc. If the data held, it would be the third Earth-like world ever discovered. "It was very strange," Anglada-Escudé told me in 2012, when I was reporting the story of Gliese 667Cc for my book, *Five Billion Years of Solitude*, "to find an unpublished, unclaimed, potentially habitable planet in a three-year-old public data set." Yet there it was.

Anglada-Escudé took his numbers to his mentors, Butler and Vogt. Butler took 21 new measurements of Gliese 667C with the Carnegie Planet

Guillem Anglada-Escudé
He claims he discovered Gliese 667Cc in archive data.

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[2] The capital *C* indicates a trinary system, with A and B stars.

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Finder Spectrograph in Chile, and Vogt retrieved 20 more measurements from archived Hires data. It all only bolstered the finding, and the team began drafting a discovery paper.

AS ROBERTSON REVIEWED THE DATA, PLANETS STARTED DISAPPEARING INTO THE STATISTICAL NOISE. THE FIRST EARTH-LIKE EXOPLANET WAS NOW GLIESE 667Cc.

But Anglada-Escudé wanted to be absolutely certain the signal was genuine. The best plan: Get new data from Harps, the European spectrograph. Since Germany was a member of the consortium that funds the instrument, and Anglada-Escudé was at the time working at a German institution, he could apply to use it. Worried it would tip off the European team, Butler and Vogt cautioned against it. But Anglada-Escudé wanted those numbers to cement the discovery. On September 28, 2011, he submitted a proposal for 20 nights on Harps with Gliese 667C on his target list and mentioned the existence of a 28-day signal detected in its vicinity.

In the following weeks, Anglada-Escudé monitored his personal website for visits by members of the Harps review committee. He figured if they were checking his credentials, that meant they were reviewing his proposal. In mid-November he saw a spike in traffic from Garching, Germany, where the review committee was based, as well as from other cities around Europe with Harps team members.

And then his Harps proposal was rejected.

About two months after Anglada-Escudé's initial application, the Harps researchers uploaded a paper to a public online repository of preprints—unreviewed but otherwise rigorous research reports. The preprint summarized Harps observations of red dwarf stars from 2003 to 2009, and the team had already submitted it to a prominent journal. Grenoble, France–based Xavier Bonfils—head of the Harps campaign to find planets around red dwarf stars[3]—was its lead author. Within its 77 pages, one paragraph and a short entry in a data table discussed the team's detection of a super-Earth in a 28-day orbit around Gliese 667C, stating that a more detailed discovery paper was in preparation.

Xavier Bonfils
His European team says it found Gliese 667Cc first.

Vogt was first to see the Harps team's preprint. He sent a terse email to Butler and Anglada-Escudé: "We've been scooped."

"I was very upset," Anglada-Escudé said. "So I reread the preprint again and started cataloging strange things."

He found what he believed to be a smoking gun: Gliese 667Cc's orbital period was correctly included as 28 days, but another datum for the planet—separation from its star—erroneously matched an orbit of about 91 days. The entry, it occurred to Anglada-Escudé, might at one time have concerned a different signal, before perhaps being hastily changed. He started to wonder if the Harps team had seen his proposal and quashed it so they could take credit for the blockbuster planet they had overlooked. "It could have all been a coincidence," he said. "But I couldn't help feeling suspicious."

Anglada-Escudé pushed harder to claim what he felt was rightfully his. He and his collaborators wrote their discovery paper and submitted it to *Astrophysical Journal Letters*, an influential publication that reviewed and published it before the Harps team's paper went to press.

The Europeans cried foul. They got a paper into *Astronomy & Astrophysics* and began a modest PR campaign to strengthen their case as Gliese 667Cc's true discoverers.

That June, Bonfils and Anglada-Escudé attended an astronomy conference in Barcelona, and the two men met privately to hash out their differences. Over espresso in a café, they talked quietly for an hour. But as they conversed, their words and attitudes hardened. Neither would back down from claiming to have found the faraway world first.

THE FIGHT would be little more than an academic footnote if it weren't for another up-and-coming astronomer, Paul Robertson, a postdoc at Penn State University. His contribution began, as so many momentous discoveries do, with an expletive: "Oh shit."

Robertson was sitting at his computer on a chilly afternoon this past February, looking at data from the star the Americans and Europeans first started fighting about, Gliese 581. He was using specialized analytical techniques to try to correlate the magnetic activity of the star to the supposed wobbles, all in an attempt to settle once and for all whether Gliese 581g—Zarmina's World—was real or just noise. As he delved into the data, the wobble from Gliese 581g indeed dissipated into static, falling far below the threshold of statistical significance. It seemed the American team had only seen a ghost. The second ever Earth-like exoplanet would have to be crossed off the star charts.

But the plots scrolling across Robertson's screen revealed something much more shocking: The Europeans' find, Gliese 581d, long considered an unimpeachable discovery and the first plausibly Earth-like planet ever found, vanished as well.

There was no avoiding it. Robertson published a paper explaining that some of Earth's foremost astronomers had gotten it wrong. "Busting other people's planets was never really my intention—I'm more interested in finding them," Robertson says. But even though he hadn't asked for a reputation as a ruthless destroyer of worlds, Robertson couldn't shake the feeling that more false-positive planets were out there, calling like Sirens to scuttle unsuspecting planet hunters in deep, turbulent seas of noise. With the potential Earths of Gliese 581 now dead as Alderaan,

ILLUSTRATION BY JOE MCKENDRY

[3] Star type depends on color and temperature. Our sun is a yellow dwarf; Gliese 667C is a smaller, cooler red dwarf.

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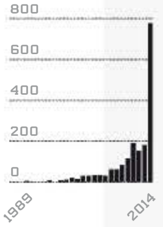
Robertson's team moved to the next world on the list: Gliese 667Cc. But even under Robertson's scrutiny, it wouldn't go away.

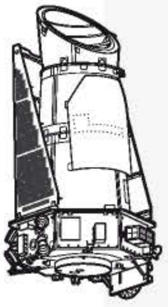
In other words, the planet whose discovery was so highly contested became, officially, the first potentially Earth-like world ever detected. The person who found it should be able to bask in the achievement ever after—if he can make his claim stick.



Number of exoplanets discovered

NOT LONG AFTER the failed coffee shop détente, I talked to an exasperated Bonfils. The whole thing was, he said, a misunderstanding, compounded by speed bumps typical of the publication process. The European team had submitted its survey for peer-reviewed publication in the spring of 2009, Bonfils explained, long before Anglada-Escudé's research. Feedback from a fellow researcher had delayed the preprint's release until late 2011. He dismissed the minor inconsistencies it contained as simple mistakes, nothing more. In his view, the most pertinent fact was that others were attempting to take credit for a discovery they simply had not made. "Harps was built by our team, and the scientific program and observations were done by our team," Bonfils said. "Most of the data reduction was already done and provided in our public data."

In other words, as Bonfils sees it, his team had already done the hard work of analyzing the data. (Vogt says this is no longer true. The Europeans, he wrote in an email—not to me, but since published—process and archive data in a way that specifically makes it "not reliable by any other than Harps team individuals." So Vogt says his team now reprocesses the public data and derives their own measurements of wobbles.)



Kepler space telescope
In February 2014 NASA announced it had discovered 715 new exoplanets.

What was at stake here was more than just the discovery. It was about access to and treatment of data. "It would be a pity if the guys who made the instruments, and designed and performed the program of observations, did not receive credit for their work," Bonfils said. "I'm a supporter of public data, but I had long feared someone would try to publish our data before us, and it has now happened. Right now this community rests on good behavior and gentlemen's agreements." Bonfils said he senses "anger, an aggression" in Butler, Vogt, and their collaborators—including Anglada-Escudé. "You see it in their papers, in the language and accusations," Bonfils said. "I think it has become more difficult for them to get the observing time they need." Without access to the right machines, in other words, the planet-hungry renegade group had no choice but to go a little rogue.

In the research community, who an astronomer believes actually discovered the planet seems to depend to some degree on which side that astronomer is closer to—the established, old-guard teams of Marcy and the Harps superstars, or Anglada-Escudé and a few other upstarts. Meanwhile, those upstarts still unabashedly seek overlooked planets in the public data from Harps and other instruments. As a result, the fight between Bonfils and Anglada-Escudé seethes beneath the cordial formalities of professional astronomy. Bonfils now calls Anglada-Escudé's behavior "unethical," citing several further clashes over questionable planets drawn from Harps data. Anglada-Escudé still believes the Harps team is stonewalling him—a claim Bonfils says is ridiculous. "We don't have this power," he says.

IN 2009 NASA launched the Kepler space telescope on a three-and-a-half-year planet-finding mission. Chasing Earth in orbit around the sun, Kepler looks for exoplanets by searching for worlds that "transit" across their stars as seen from our solar system, revealing themselves in silhouette. The half-billion-dollar telescope has found almost 1,000 exoplanets this way, including—as of April 2014—an Earth-sized world called Kepler 186f, orbiting in the habitable zone of a star about 500 light-years away. That's too far off for an easy follow-up investigation, of course. But Kepler's scientists would argue that's not really the point. Their discoveries have moved the field well past the point where any individual planet or person holds the same allure as the heroic, obsessive world seekers of years past. Not that long ago, the discovery of a single exoplanet was an international media sensation. In February, by contrast, the Kepler mission announced 715 new exoplanets. Outside the astronomy community, nobody really cared.

Kepler's results strongly suggest that planets of all types—including ones identical to Earth in their broad description—are common. The search for Earth 2.0 is, in a sense, already over, even though it has barely begun. Now astronomers want a galaxy-encompassing statistical planetary census, accounting for the profound diversity of planetary systems along the way. Such an approach doesn't focus on individual exoplanets. But it can tell you, as Kepler's rich statistics already have, that about one in five sunlike stars should harbor an approximately Earth-sized planet in the habitable zone, placing the nearest life-friendly world somewhere within perhaps a dozen light-years of our solar system. That calculation actually comes from Geoff Marcy's group—even the central figure from planet-finding's Heroic Age has changed with the times.

Yet when it comes to discovery, being first still matters. It's built into the kind of exploration that planet hunting embodies. It comes from the same insatiable urge that drove our ancestors to climb down from the trees, then race from horizon to horizon, until they finally ran out of frontiers. Even if we have exhausted most new places to explore on Earth, our desire to discover, to make the unknown known with our names, our dreams, our stories, is inexhaustible. We call Jupiter's four largest moons Galilean because Galileo saw them first. We look to the stars because we see in them a future, and being first gives someone the power, however mystical and irrational, to make that future manifest and give it life and meaning that could echo through generations. Even if history doesn't always choose the right person.

Bonfils and Anglada-Escudé actually agree on a lot. They both think planetary data should be open. They both want more and better instruments to monitor each and every nearby sun for planet-induced tremors. They both hope for a grand space telescope that will actually *see* all the worlds within a hundred light-years of Earth—and anyone who lives on them. Like Robertson, they don't want to destroy other people's planets. All they really want is to find new ones—faraway pale blue dots, kin to our own, pirouetting silently in a typical habitable zone, all tumbling together through endless night. ▣

ILLUSTRATION BY CHRIS PHILPOT; SOURCE: EXTRASOLAR PLANETS ENCYCLOPAEDIA

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In 1890, the Swiss Federal Council decided that soldiers should be equipped with a pocket knife. Karl Elsener, our great-grandfather and founder of Victorinox, would not be held back from offering his services and securing his little forge on the Tobelbach its first big order. However, he knew he would not be able to make the desired quantity on his own, so he collaborated with friends who were knifemakers and founded the Association of Swiss Master Cutlers. Together, they managed to kit Swiss soldiers out with their first Swiss-made knives. A few years later, he developed a new kind of pocket knife, one that came with additional functions, as well as being lighter and more elegant – the Original Swiss Army Knife. For the past 130 years, it has been a faithful companion to Victorinox, embodying the courage that inspired our great-grandfather to set out on a new path, one step at a time, day by day.

Carl Elsener, CEO of Victorinox AG, March 2014

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THIRD DIMENSION

SPACE INVADERS

FUTURE COSMIC TRAVELERS WILL HAVE TO WEIGH THE COST OF EXPLORATION AGAINST WHAT'S TO BE GAINED—OR LOST.

BY CHARLES C. MANN

ILLUSTRATION BY LEIF PODHAJSKY

ZHENG HE! Zheng He! Is there a better icon for interstellar voyaging? ¶ Between 1405 and 1433, Zheng set out from China on massive naval expeditions that reached as far as Mecca and Mombasa, journeys with more than 300 vessels and 28,000 crew, excursions far bigger and longer than those of Columbus more than a half century later. Staggering in price, formidable in technical sophistication, unprecedented in level of national commitment—Zheng's voyages remain the closest functional equivalent to the cost, effort, and risk required to travel into deep space. Trying to picture what settling other planets might entail? One place to look is 15th-century China. ¶ Zheng was an unlikely candidate for a life of far-flung adventure. At the time of his birth, China was torn by war between the Yuan dynasty and surging Ming rebels. Zheng was born into a Muslim family in the remote Yunnan province, then a battleground between Yuan and Ming. When he was about 10, invading Ming forces captured him and slaughtered most of his family. The boy was castrated. Forced to serve the Ming crown prince, Zheng eventually became his confidant and trusted adviser. After the last Yuan emperor fled in 1368, Zheng became part of an elite group of eunuch adventurers and troubleshooters at the Ming court in Beijing. ¶ The Ming government backed Zheng for decades. Seven times the emperor arrogantly overruled his accountants and summoned the vast amounts of material necessary to provision thousands of people on years-long voyages. Ultimately, Zheng took the Ming banner as far as West Africa and the Middle East. These areas were poorer than China, but they were thriving and productive. Alas, traveling to Africa to buy its iron, no matter how high the quality, would be like driving a hundred miles to pick up a gallon of exceptionally good milk—not a sensible use of time, money, or effort. In 1433, the voyages abruptly ceased; Ming bureaucrats had finally convinced the elite that they didn't make economic sense.

If we traveled to other worlds, could we avoid the Zheng He problem? Back in 1978, the Nobel-winning economist Paul Krugman, a science fiction fan, playfully laid out the basic economics of interstellar trade. To justify the cost, Krugman pointed out, would-be starfarers must bring back something worth more than what they would have made by putting the same money in an interest-bearing account and staying on Earth. Going to distant planets, in other words, means fighting one of the greatest forces in human affairs: compound interest.

Today, the cheapest rockets available charge a little less than $1,000 to send 1 pound of material into low-earth orbit. Sending that pound to other planets, let alone the stars, would cost vastly more. To be sure, time and expense might be reduced by building space elevators and (should the laws of physics permit) taking advantage of handy wormholes. But the lesson of Zheng He remains: Exploration of distant lands will be a short-lived venture unless it yields something really, really valuable.

If future space voyagers decided to exploit a barren, lifeless planet, few would be upset. But such an endeavor is unlikely. As far as we know, a world without life would be a world without oxygen, a stable climate, or the possibility of growing food. Barring the discovery of some immensely valuable substance that doesn't exist on Earth, there would be no reason to set up shop there, let alone despoil it. A world with functioning ecosystems would be more attractive. But if local species were valuable, it would be more sensible to carry back to Earth a snippet of their DNA than whole animals. The entire *Alien* series can be considered as a proof by negative example of this assertion.

The real jackpot, of course, would be finding a nonhuman civilization: a planetful of new ideas, techniques, and expression. Here the temptation to interact—that is, to intervene—would be enormous. China again provides an example. Travel costs today are low compared to those in the 15th century. West Africa, meanwhile, is still full of valuable resources, products, and land, so Chinese ships are again going to Africa. In the past decade, the nation has shipped in a million or more migrants. Buying and leasing swathes of land to grow food for export to the homeland, grabbing deals to extract minerals, locking up local water supplies—the newcomers have been throwing their weight around. Even though the Chinese have built many badly needed roads, bridges, and power plants, their moves have created a furor. "Landgrab!" cry African newspapers. Chinese workers have been attacked in Zambia, Cameroon, Niger, Sudan, and Angola.

History suggests that if anything of value is involved, contacts between distant societies are fraught. Think of Spain and the Aztecs. Cortés could have traded peacefully for Aztec gold and silver, but that would have involved the expense of ferrying over goods from Spain for barter. Conquest was more attractive (economically, if not morally), and greatly abetted by an epidemic of smallpox introduced to the Aztecs by the Spaniards. Stuck at the end of a trillion-mile supply chain, voyagers from Earth might be less likely to replicate the triumph of Cortés than the fates of Thomas Drummond and William Paterson. The two men were leaders of Scotland's biggest mission to the Americas: the attempt to implant some 2,500 highlanders in Panama starting in 1698. A grandiose effort for a poor country, the expedition sucked up as much as half of the nation's available investment capital. It was that rarest of events, an unmitigated disaster. The locals in Panama weren't interested in trade. Unable to grow food in the unfamiliar ecosystem and beset by diseases they had no experience with, the Scots died by the hundreds. Drummond vanished; Paterson lost his wife. As the few survivors limped back to Edinburgh in 1700, Scotland's economy collapsed, forcing it to merge with England.

To boldy go
Zheng He's ship undertook one of mankind's greatest explorations into the unknown.

Is interstellar travel too risky and economically irrational ever to happen? Turn again to Zheng He. His voyages were sponsored by the brutally ambitious emperor, who ignored his flunkies' complaints about the cost. Key to most great leaps is at least one overconfident investor; in 15th-century Asia, the emperor played that role. Our society, vastly richer than early-modern China, has no lack of would-be successors. Look at the billionaires jumping into commercial spaceflight: Jeff Bezos with Blue Origin, Richard Branson with Virgin Galactic, Naveen Jain with Moon Express, Elon Musk with SpaceX. Eventually humankind will push into space no matter what the expected cost-benefit ratio. Those first adventurers will have one advantage over their early-modern predecessors. Future starfarers will know about Zheng, Cortés, Drummond, and Paterson. They will understand that the outbound voyage, no matter how complicated and expensive, is only the beginning.

CHARLES C. MANN (charlesmann.org) *is the author of* 1493: Uncovering the New World Columbus Created.

ILLUSTRATION BY CHRIS PHILPOT

*Available feature.

Go Further

ARE ONE-TENTH LIVING TISSUE, NINE-TENTHS WATER; LIFE IS ONE-TENTH HERE AND NOW, NINE-TENTHS A HISTORY LESSON. FOR MOST OF THE TIME THE HERE AND NOW IS NEITHER NOW NOR HERE.”

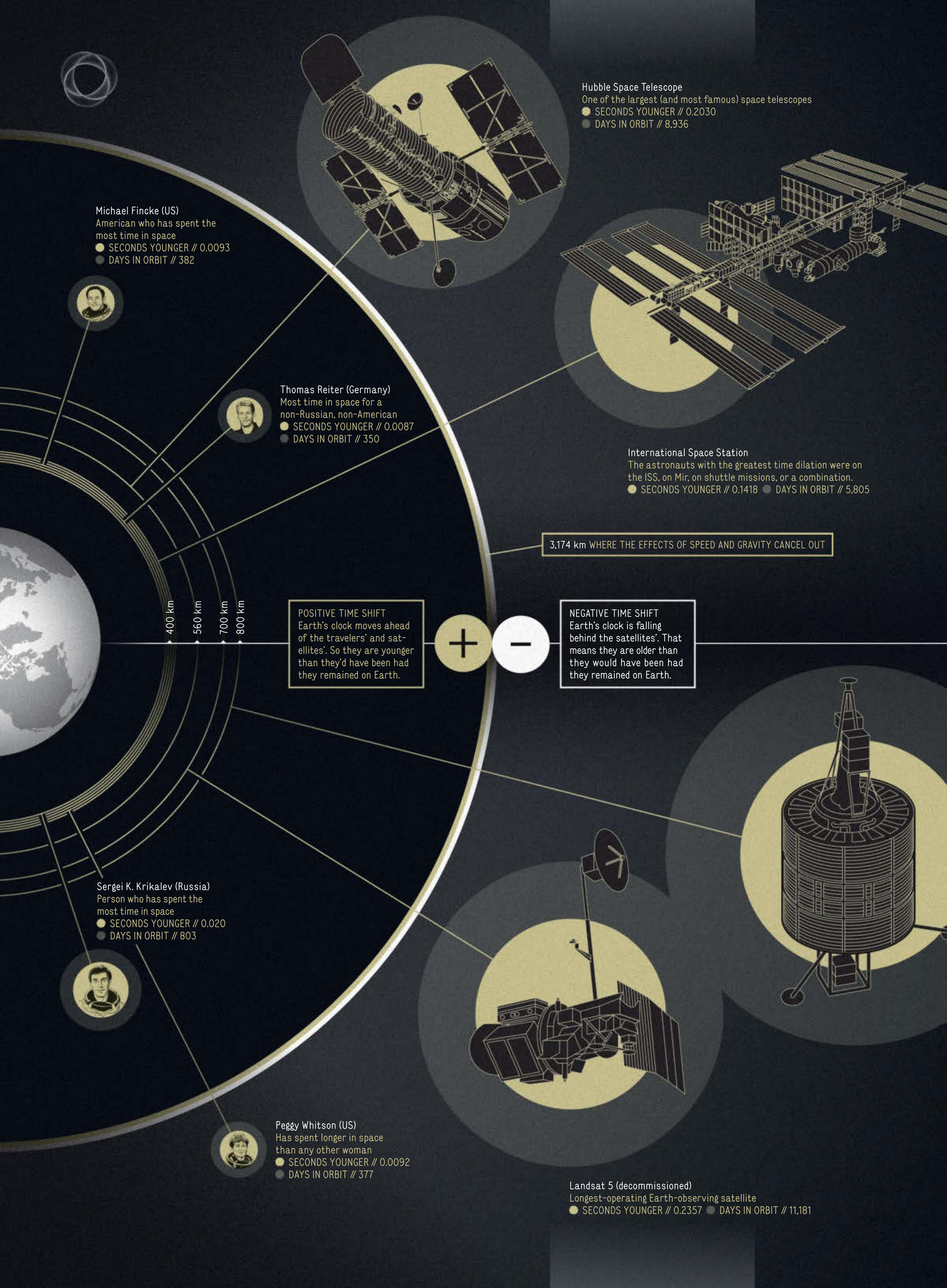
GRAHAM SWIFT

FOURTH DIMENSION: TIME

SYNCHRONICITY, TIME DILATION,
AND PLAYING GAMES WITH SPACETIME.

172

“LIFE INCLUDES A LOT OF EMPTY SPACE. WE ARE ONE-TENTH LIVING



Hubble Space Telescope
One of the largest (and most famous) space telescopes
● SECONDS YOUNGER // 0.2030
● DAYS IN ORBIT // 8,936

Michael Fincke (US)
American who has spent the most time in space
● SECONDS YOUNGER // 0.0093
● DAYS IN ORBIT // 382

Thomas Reiter (Germany)
Most time in space for a non-Russian, non-American
● SECONDS YOUNGER // 0.0087
● DAYS IN ORBIT // 350

International Space Station
The astronauts with the greatest time dilation were on the ISS, on Mir, on shuttle missions, or a combination.
● SECONDS YOUNGER // 0.1418 ● DAYS IN ORBIT // 5,805

3,174 km WHERE THE EFFECTS OF SPEED AND GRAVITY CANCEL OUT

POSITIVE TIME SHIFT
Earth's clock moves ahead of the travelers' and satellites'. So they are younger than they'd have been had they remained on Earth.

NEGATIVE TIME SHIFT
Earth's clock is falling behind the satellites'. That means they are older than they would have been had they remained on Earth.

Sergei K. Krikalev (Russia)
Person who has spent the most time in space
● SECONDS YOUNGER // 0.020
● DAYS IN ORBIT // 803

Peggy Whitson (US)
Has spent longer in space than any other woman
● SECONDS YOUNGER // 0.0092
● DAYS IN ORBIT // 377

Landsat 5 (decommissioned)
Longest-operating Earth-observing satellite
● SECONDS YOUNGER // 0.2357 ● DAYS IN ORBIT // 11,181

FOURTH DIMENSION

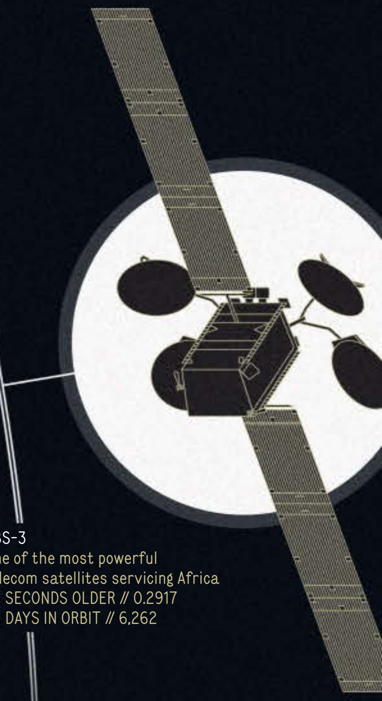
BEAT THE CLOCK

THE REAL PEOPLE AND OBJECTS THAT HAVE TRAVELED (A TINY BIT) IN TIME.

BY SETH KADISH

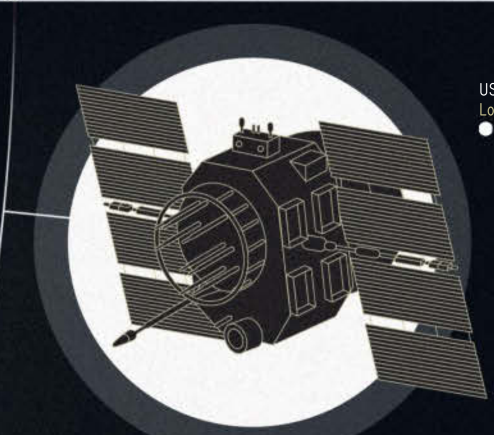
INFOGRAPHIC BY CARL DE TORRES

To get ahead in life, spend some time on the International Space Station. Why? Well, according to the theory of relativity, astronauts on the ISS age more slowly due to the spacecraft's high orbital speed. It's called time dilation, and it means that when they return they're a bit younger than they would have been—as if they've traveled into the future. (The effect is very small—it would take more than 100 years on the ISS to warp ahead by just one second.) But not all space travel will keep you young. Like speed, gravity also slows time, so your clock revs up as you get farther from a large mass like Earth. As a result, satellites in higher orbits age more quickly. Got your heart set on space travel but want to age at a normal, earthly pace? Good news! There's a sweet spot, 3,174 kilometers above Earth's surface, where the effects of increased speed and reduced gravity cancel each other out. You can hang out there as long as you like without fear of relativistic shenanigans.



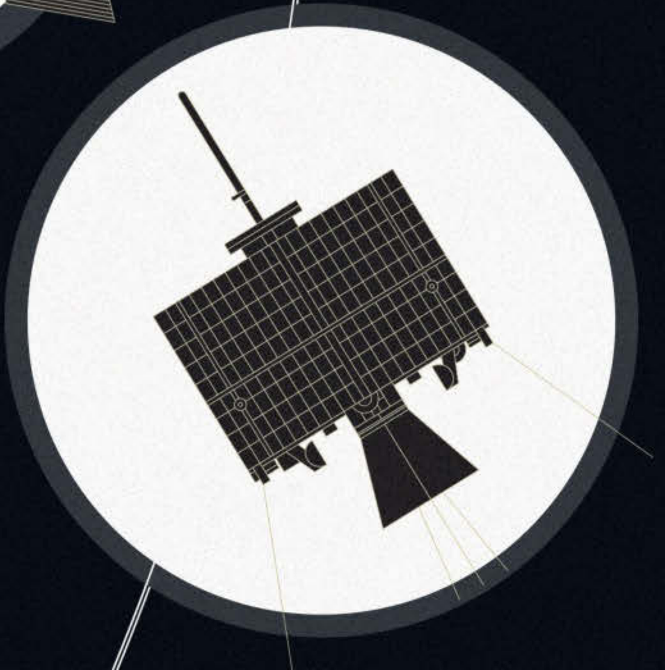
ABS-3
One of the most powerful telecom satellites servicing Africa
● SECONDS OLDER // 0.2917
● DAYS IN ORBIT // 6,262

Cosmos 158 (decommissioned)
First Soviet prototype navigation satellite
● SECONDS YOUNGER // 0.3454
● DAYS IN ORBIT // 17,316



USA-66
Longest-operating GPS satellite
● SECONDS OLDER // 0.3364 ● DAYS IN ORBIT // 8,720

Syncom 3 (decommissioned)
First geostationary communications satellite
● SECONDS OLDER // 0.8532 ● DAYS IN ORBIT // 18,315



NUMBERS AS OF OCTOBER 11. ORBITAL SPACING NOT TO SCALE.

PORTRAITS BY JOE MCKENDRY

MIND

PHYSICISTS CAN'T SHOW IT.
WRITERS CAN'T DESCRIBE IT.
ARTISTS CAN'T DRAW IT.
TO EXPERIENCE FOUR-DIMENSIONAL SPACE,
YOU HAVE TO PLAY IN IT.

BY

CHRIS SUELLENTROP

GAME

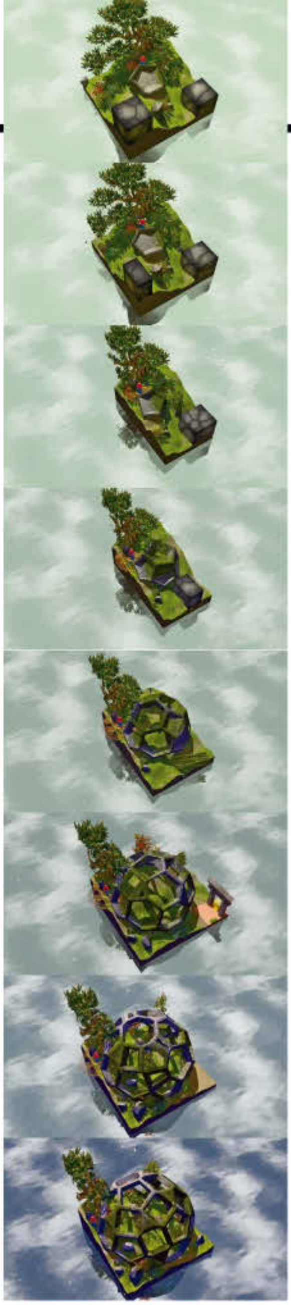
DAN WINTERS

L

THERE'S A ROW of books on a shelf in Marc ten Bosch's living room that contains a crash course in higher dimensions. Titles like *Flatland. Einstein, Picasso: Space, Time and the Beauty That Causes Havoc*. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art*. A young-adult novel called *The Boy Who Reversed Himself*. They're all devoted to helping our brains break out of the three dimensions in which we exist, to aid our understanding of a universe that extends beyond our perception.

This is not just a hypothetical pursuit. Most of us think of time as the fourth dimension, but modern physics theorizes that there is a fourth spatial dimension as well—not width, height, or length but *something else* that we can't experience through our physical senses. From this fourth dimension, we would be able to see every angle of the three-dimensional world at once, much as we three-dimensional beings can take in the entirety of a two-dimensional plane. Mathematician Bernhard Riemann came up with the concept in the 19th century, and physicists, artists, and philosophers have struggled with it ever since. Writers from Wilde to Proust, Dostoevsky to Conrad invoked the fourth dimension in their work. H. G. Wells' Invisible Man disappeared by discovering a way to travel along it. Cubism was in part an attempt by Picasso and others to visualize what fourth-dimensional creatures might see.

Still, most of us are no closer to fundamentally comprehending the fourth dimension than we were when Riemann first conceived it. People have written papers, drawn diagrams, taken psychedelics, but what we really want to do is witness it. Mathematician Rudy Rucker wrote that he had spent 15 years trying to imagine 4-D space and been granted for his labors "perhaps 15 minutes' worth of direct vision" of it.



In *Miegakure*, facing your character into the fourth dimension folds space in what seem like impossible ways—terrain shifting underneath your feet, say, or a culvert in the ground blossoming into a glorious polyhedron.

But for the past five years, ten Bosch has been trying to take us directly into it, in the form of a videogame called *Miegakure*. The game, essentially a series of puzzles, augments the usual arsenal of in-game movement by allowing the player's avatar, with the press of a button, to travel along the fourth spatial dimension. Building something so ambitious has consumed ten Bosch's life. Chris Hecker, a friend and fellow game designer, marvels that ten Bosch "can't even see the game he's making." Ten Bosch, who is 30, describes his daily schedule as "wake up, work on the game, go get lunch somewhere, work on the game, go to sleep." Even after toiling for half a decade, he is still only about 75 percent done.

But among the tight-knit community of indie game developers, *Miegakure* is a hotly anticipated title. The select few who have played it have showered it with praise.[1] Ten Bosch has twice been invited to preview it at the prestigious Experimental Gameplay Workshop at the annual Game Developers Conference in San Francisco. He won the "amazing game" award at IndieCade, the biggest annual showcase of independent games.

Miegakure has the potential to be "one of the great puzzle games of all time," writes Jonathan Blow, a friend of ten Bosch and the designer of *Braid*, a game in which players manipulate time to solve puzzles. "Games that are truly mind-expanding are very rare and very difficult to make, but this is one of them."

If *Miegakure* can live up to ten Bosch's ambitions, it will be more than just another brainy diversion—it will be the realization of a century-long intellectual quest. *Miegakure* does not visualize 4-D space or analogize it to something more familiar. Rather, the game attempts to evoke the experience of an actual, explorable world that includes one additional spatial dimension.

"There certainly isn't a fourth dimension in the way there is in the game," ten Bosch says. We can't rotate objects so that they appear out of nowhere in the real world or disappear in front of our eyes. But he wants the game to give people the intuition that a fourth spatial dimension might exist. The easiest way to wrap our minds around such a slippery concept, he thinks, is to reach out and touch it.

CHRIS SUELLENTROP (@suellentrop) *wrote about* Bioshock Infinite *in issue 21.01.*

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[1] *xkcd* creator Randall Munroe (see p. 192) even devoted a comic strip to *Miegakure*.

GROOMING BY TAMARA BROWN/ARTIST UNTIED

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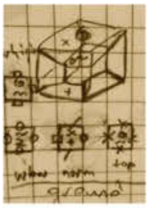
AT THE ADVENT of videogaming, we existed digitally as two-dimensional beings. Poor 2-D Mario couldn't step sideways to dodge a barrel hurled by Donkey Kong; viewed from above, Pac Man could not leap to avoid a pincer engagement by Inky, Blinky, Pinky, or Clyde. And because gamers feel a magical and mysterious connection between our physical selves and the virtual characters we control (we use the word "I" to describe them both), in a very real sense we couldn't do those things either.

There were hints, even in those early days of gaming, that a third dimension might exist, a *z* axis along which our avatars might wander, if only we knew where to look. Soon, Moore's law enabled us to find it: In the 1990s, 3-D games like *Doom* and *Super Mario 64* opened up new vistas for electronic exploration, turning players into digital Magellans navigating truly round worlds. Later, titles like *Portal*, *Fez*, and Blow's *Braid* allowed players to interact with and manipulate space and time. In *Portal*, players used a gun to open tunnels in space; in *Fez*, the player's 2-D avatar could swivel his world like a 3-D cube to change the surface he walks on. *Braid* was in part a response to Alan Lightman's novel *Einstein's Dreams*, which asks: What if we experienced time and space as being intricately connected in new and strange ways?

Miegakure picks up these themes and extends them along a strange and previously unknowable axis. You control a small, seemingly Japanese man who lives in a cubic landscape dotted with trees and rocks and Torii gates, the kind you see at Shinto shrines to mark, in ten Bosch's words, "the separation between the sacred and the normal." Although *Miegakure* is built upon the math of four-dimensional space, the game is also infused with the ethos of Japanese gardens.[2] The game's title is a reference to that tradition, an aesthetic principle that means "hide and reveal."

"You can never see the whole garden at once," ten Bosch says. "So you're always imagining the parts you can't see. It makes the garden feel larger than it really is and maybe more intriguing than it really is."

That's also been a hallmark of game design—think of the secret worlds and warp portals hiding within *Super Mario Bros.'* pipes and bricks. *Miegakure* is even more concerned with the mysteries of the unseen. At a fundamental level, the true shape of reality is invisible to us, thanks to our utter inability to visualize another spatial dimension. We perceive *Miegakure* as 3-D slices of 4-D worlds, the way a 2-D creature would understand a book as just a series of pages.



Gleaming the Hypercube
Early sketches from Marc ten Bosch's notebook show some of the 4-D thinking behind *Miegakure*.

WHY CAN'T WE SEE HIGHER DIMENSIONS? MAYBE THEY'RE TOO SMALL TO MEASURE, OR MAYBE SPACE IS WARPED IN SUCH A WAY THAT THEY REMAIN HIDDEN FROM US.

But our inability to see all the dimensions of a 4-D world doesn't mean that we can't navigate it, that we can't reach out and feel it with our digital fingertips. What makes *Miegakure* extraordinary is that it allows our species, for the first time in its history, to enter a four-dimensional space and manipulate it, like blind scientists patting a hyper-elephant. "I think that's one of the magical things about interactivity," Hecker says. "You can understand it in a way that's not purely conscious."

The interactions in *Miegakure* are basic: You can move the character, you can make him jump, you can press a button to enter one of the Torii gates (most of which lead to a puzzle). And you can press another button to travel along the unseeable fourth dimension. When you press it, the world appears to morph and fold in on itself, revealing colored slices to walk on. These slices look like parallel worlds; they're even visually distinct so that players can distinguish them as separate realms. One looks like desert, another like grass, another like ice. Walking onto each slice and then pressing the button seems to transport you into each new universe.

But here's the thing: They're *not* new universes. They're 3-D cross-sections—"hyperslices," maybe?—of a 4-D shape. The "morph" button, which appears to make the world around you swirl and the objects within it disappear, does not in fact move your character even a millimeter. You're not teleporting. You're just changing perspective—except you're not looking left or right, not up or down or forward or back. You're looking into the unseeable fourth dimension and only then traveling along it.

Over time, the game nudges you toward an understanding of this by including 3-D objects

[2] Ten Bosch traveled to Kyoto in October to study its ancient temples for inspiration.

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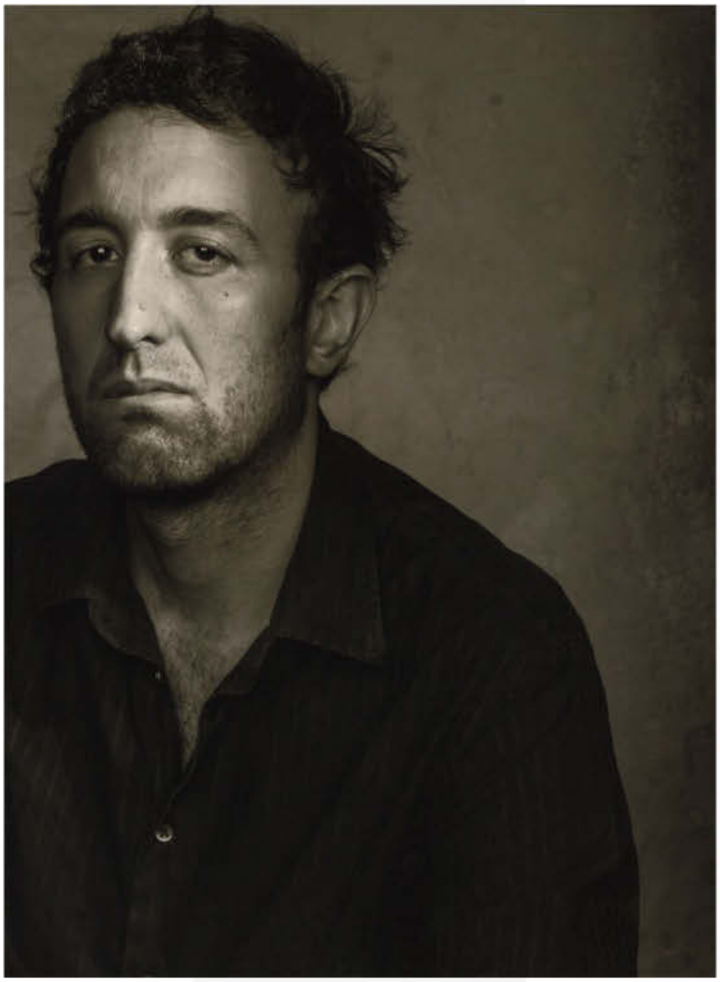
that move in more than one "universe" when your character pushes them. You find maps that help to illustrate how the spaces intersect. And soon you're performing the miracles that mathematicians say a 4-D being could perform in three-dimensional space: walking through walls, making blocks seem to float in the air, disappearing and reappearing, and interlocking two seemingly impenetrable rings. The math is solid—every shape in the game is defined by four coordinates instead of three—but just as when an illusionist performs that same ring trick, it feels like magic.



FOR ALL THE ATTENTION *Miegakure* has received, its designer is far from a videogame star. Ten Bosch moved to the United States from Nice, France, more than a decade ago to go to DigiPen Institute of Technology, a for-profit college in Redmond, Washington, known for training students to work at the megacorporations that produce the industry's biggest, most expensive hits, like *Call of Duty* and *Madden NFL*. After school, ten Bosch landed a four-month internship at Electronic Arts in Southern California.

The company offered him a job, he says, but he turned it down, swept up in the excitement surrounding a burgeoning indie games scene: Blow's *Braid* was just hitting Xbox 360s. Ten Bosch also wanted to create a game that mattered, so in late 2008 he set out to build a prototype from a thought experiment: Normally you use three numbers to create digital spaces, but what if there were four?

I finally have the chance to play the result of that question one afternoon in September. Ten Bosch shines a projector onto a wall in his spartan apartment and hands me a controller. The game begins with an epitaph from Oliver Wendell Holmes: "Man's mind, once stretched by a new idea, never regains its original dimensions."

Even among string theorists, there's a debate around the margins of the theory of higher spatial dimensions: Why can't we see them? Maybe they're too small to measure, or maybe space is warped in such a way that they remain hidden from us. Maybe we live on a three-dimensional membrane that is floating in 11-dimensional space,[3] making us something like water droplets that can't escape from the shower curtain we're attached to. Maybe our universe of four-dimensional spacetime split from a smaller six-dimensional universe at the moment of the Big Bang and our only hope to escape the heat-death of this universe is to find a way to get inside the other one.

Miegakure makes no efforts to explore these existential questions. Instead, it guides players to an intuitive, if incomplete, grasp of the geometry involved. It's a little like shooting a free throw in a game of four-dimensional basketball: You don't know how to calculate the curve the ball must follow or even how to imagine the line it draws through space as it falls through the net, but you can somehow make the shot.

These are, for now, ineffable concepts. But after several hours inside *Miegakure,* 4-D space has become somehow a bit more … effable. Faced with a level in which I had to appear atop a floating box on another cross-section of the hyperworld—on the other side of the screen—I found that I knew where to stand in 4-D space to pull it off. I couldn't tell you *why* I should stand in a particular spot, nor could I visualize the space that I was skillfully navigating. Ten Bosch insists that I shouldn't worry about it.

"I think you have the instinct," he says, looking pleased. "I think you get it."

[3] The concept of 11 dimensions is a postulate of unified string theory, dubbed "M-theory" in the mid-1990s.

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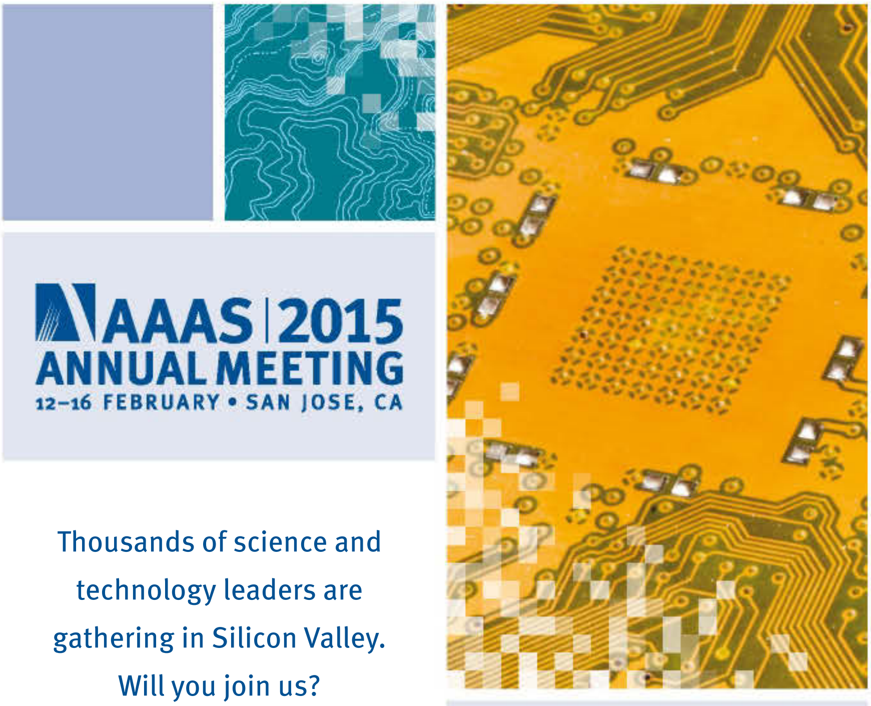

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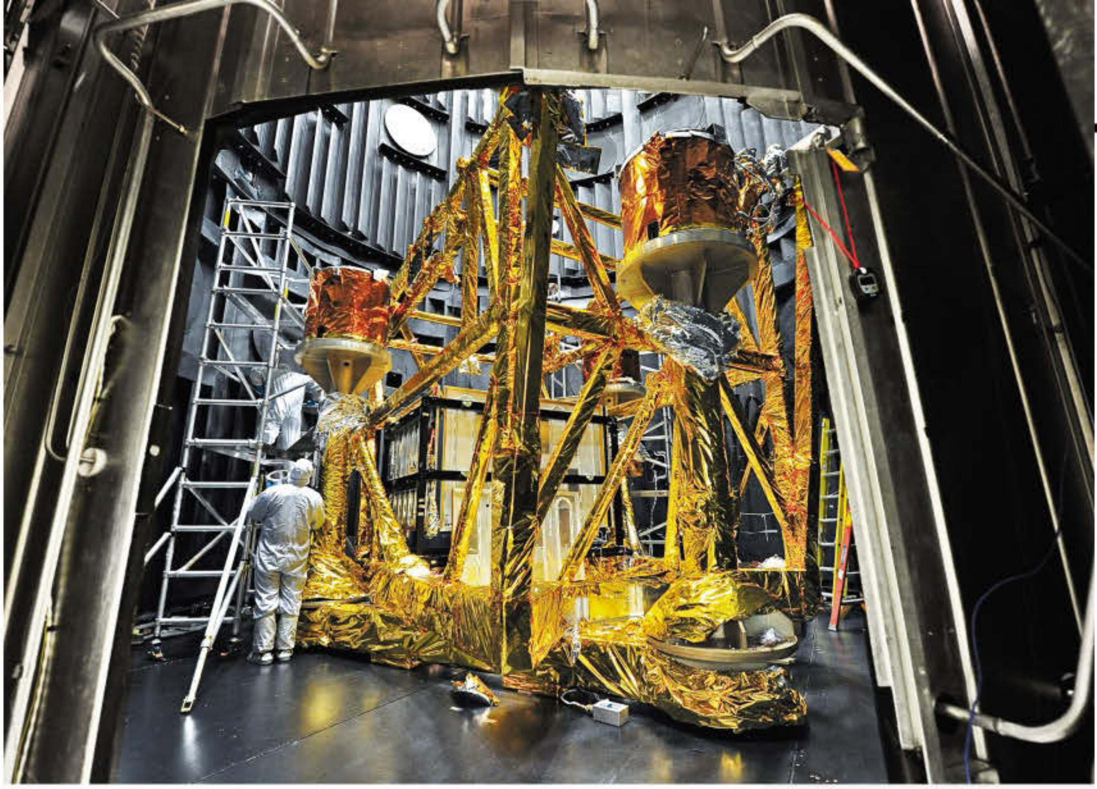


FOURTH DIMENSION

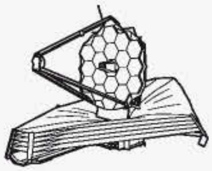
FROZEN IN TIME

HOW A SUPERCHILLED TELESCOPE WILL WITNESS THE DAWN OF THE UNIVERSE.

BY ERIC NIILER

TO SEE BACK in time, you need a massive telescope—one big enough to capture light from when the first galaxies were formed, 13.5 billion years ago. Astronomers are clamoring to see this light, so NASA is obliging them by building the James Webb Space Telescope. The Webb will operate 1 million miles from Earth in a gravity-tethered spot called the L2 point, where the telescope can get cold enough that its own heat won't drown out faint traces of infrared radiation—once-visible light that's been stretched out by the universe's expansion. To ensure it will survive out there, this astro-time machine has to be prechilled: In the past year, NASA engineers have tested individual components in vacuum chambers that reach L2-like temperatures (below 50 Kelvin). Once in place, the Webb, with its 21-foot mirror, will be 100 times more powerful than the Hubble Space Telescope, able to capture images of very dim, very old light. It will also probe the atmospheres of exoplanets to check for oxygen, water, and maybe even alien pollution. Final assembly begins in December, and the fully built Webb launches from French Guiana in October 2018—heading far out in space to peer back in time.

CHRIS GUNN/NASA; ILLUSTRATION BY CHRIS PHILPOT



THE JAMES WEBB SPACE TELESCOPE

Super sunshade
The Webb's four delicate cameras need to get frigid to pick up the faintest infrared light signals. So once in position, a five-layer sun shield will unfurl, blocking the sun's heat. A thin layer of gold on each of the telescope's mirror segments reflects the light of distant galaxies onto the instruments.

Carbon tough
The greatest risk for the Webb is thermal cracking as it deploys the sun shield in deep space. "The whole thing shrinks when it cools down," NASA project manager Paul Geithner says. "It tries to tear itself apart." He's testing a recipe of boron graphite fibers, epoxy glue, and metal joints to increase flexibility and keep it together.

Cold case
To prep for deep freeze, the Webb's parts—mirrors, cameras, and electronics—are being tested inside the cold chamber at the Goddard Space Center (left). The chamber has two cold boxes: The outer shell uses liquid nitrogen to reach 77 Kelvin, and the inner chamber fills with helium gas to lower the temperature below 30 Kelvin (−405 degrees Fahrenheit).

End point
After the Webb travels to the L2 point, Earth will gravitationally "pull" it along while circling the sun. When its shield blocks the sun's rays, the telescope will get supercold—colder than the Hubble does in low earth orbit. But unlike with the Hubble, there's no way to send an astronaut to fix the Webb if something fails (yet).

Prime objective
The Webb will hunt for light emitted when the first galaxies were making the building blocks of the universe, 300 million to 400 million years post–big bang.

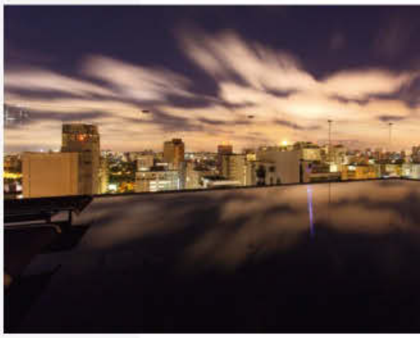
3:29 PM Sept. 22, Midway Atoll

4:29 PM Sept. 22, Honolulu, Hawaii

5:29 PM Sept. 22, Adak, Alaska

9:29 PM Sept. 22, Mexico City, Mexico

10:29 PM Sept. 22, New York, New York



11:29 PM Sept. 22, Rio de Janeiro, Brazil

3:29 AM Sept. 23, London, England

4:29 AM Sept. 23, Johannesburg, South Africa

5:29 AM Sept. 23, Istanbul, Turkey

9:29 AM Sept. 23, Bangkok, Thailand

10:29 AM Sept. 23, Beijing, China

11:29 AM Sept. 23, Tokyo, Japan

FOURTH DIMENSION

SYNCHRONICITY

EDITED BY ANNA GOLDWATER ALEXANDER 3:29 pm: Eric Dale; 4:29 pm: Linny Morris; 5:29 pm: Calvin Kashevarof; 6:29 pm: Brian Adams; 7:29 pm: Ian Allen; 8:29 pm: Grant Harder; Reney Warrington; 5:29 am: Serkan Taycan; 6:29 am: Anastasia Rudenko; 7:59 am: Akshay Mahajan; 8:29 am: Saiful Huq; 9:29 am: Noah Sheldon; 10:29 am: Peng & Chen;

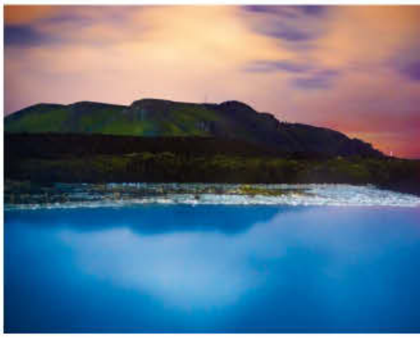
6:29 PM Sept. 22, Anchorage, Alaska

7:29 PM Sept. 22, Gray Whale Cove Beach, California

8:29 PM Sept. 22, Edmonton, Alberta, Canada

12:29 AM Sept. 23, Nuuk, Greenland

1:29 AM Sept. 23, Praia, Cape Verde



2:29 AM Sept. 23, Reykjavík, Iceland

6:29 AM Sept. 23, Moscow, Russia

7:59 AM Sept. 23, New Delhi, India

8:29 AM Sept. 23, Dhaka, Bangladesh

12:29 PM Sept. 23, Sydney, Australia

1:29 PM Sept. 23, Honiara, Solomon Islands

2:29 PM Sept. 23, Auckland, New Zealand

ON THE AUTUMNAL EQUINOX IN THE NORTHERN HEMISPHERE (AND THE VERNAL EQUINOX IN THE SOUTHERN HEMISPHERE), 24 PHOTOGRAPHERS—ONE IN EACH OF THE GLOBE'S 24 TIME ZONES—POINTED THEIR CAMERAS DIRECTLY WEST AT THE EXACT SAME MOMENT AND PRESSED THE SHUTTER.

9:29 pm: Jorge Dávalos; 10:29 pm: Floto & Warner; 11:29 pm: Tuca Reinés; 12:29 am: Mads Pihl; 1:29 am: Daniel Reyes; 2:29 am: Bernhard Kristinn; 3:29 am: Ben Anders; 4:29 am:
11:29 am: Takashi Kikuchi; 12:29 pm: Sean Fennessy; 1:29 pm: Kim Litera; 2:29 pm: Shaun Pettigrew

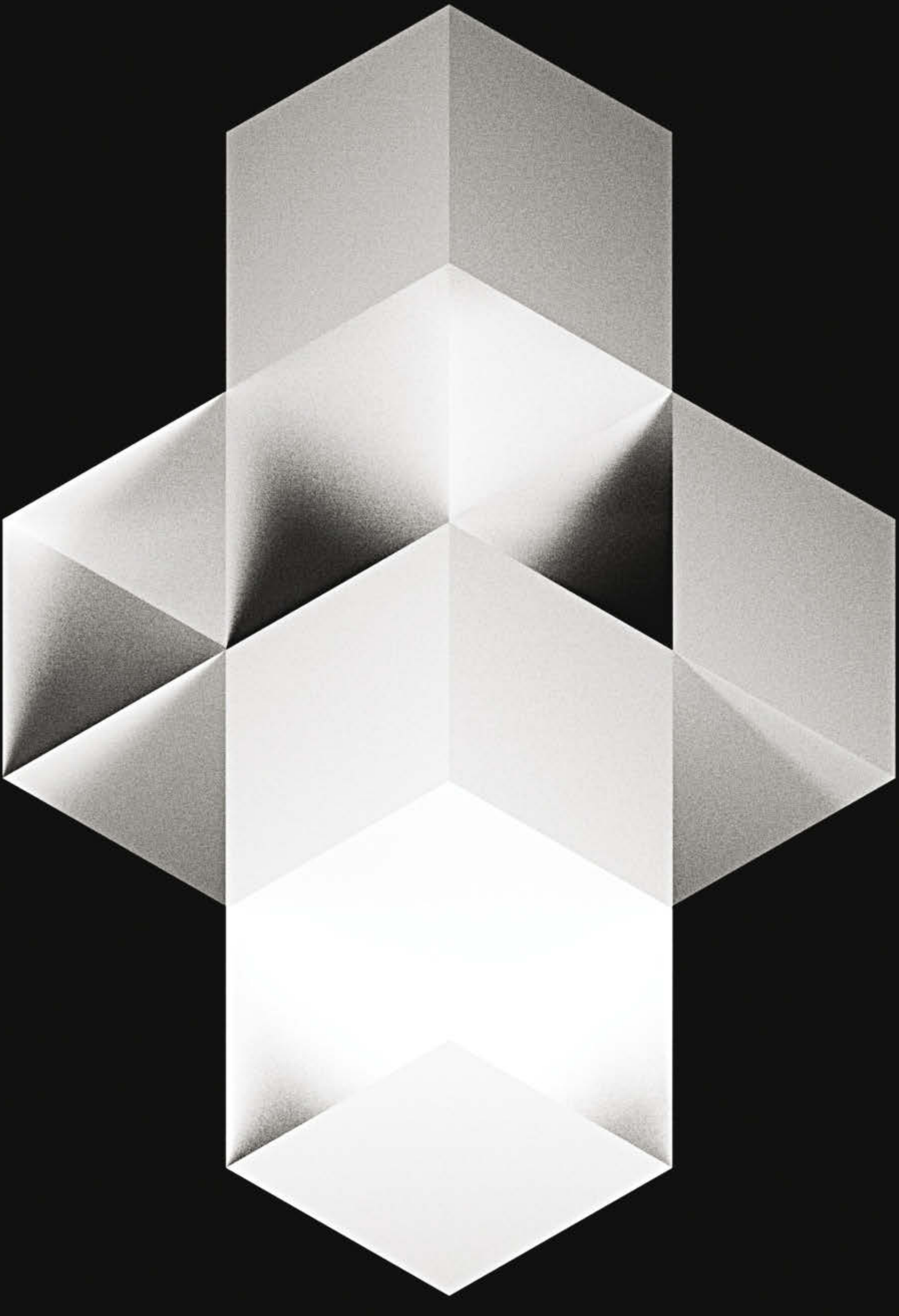
LABYRINTH THAT
WOULD ENCOMPASS
THE PAST AND THE
FUTURE AND IN SOME WAY
INVOLVE THE STARS."

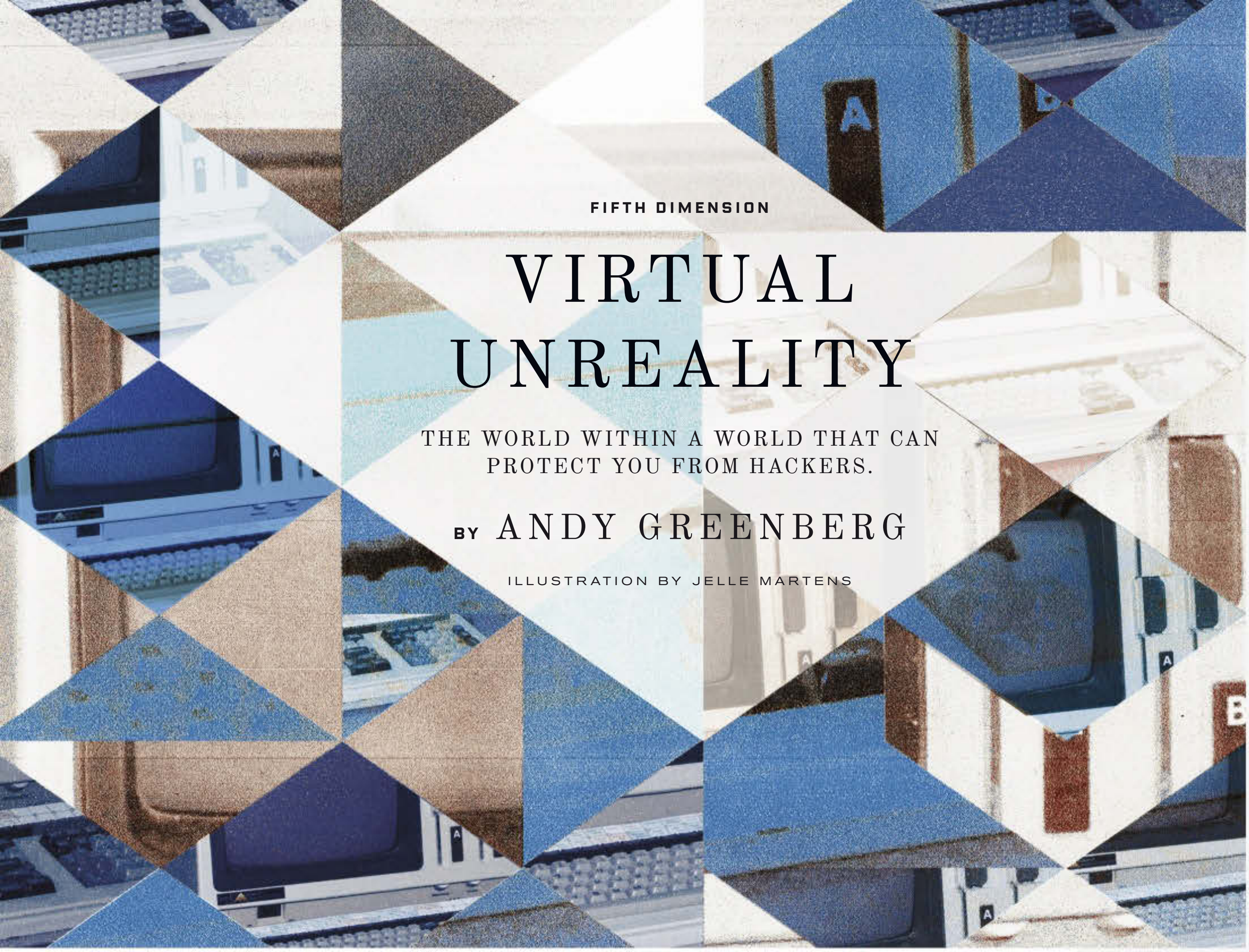
JORGE LUIS BORGES

FIFTH DIMENSION: MULTIVERSE

TALES OF ALTERNATE REALITIES, SHIFTING PERSPECTIVES, AND THE LIMITS OF ASTROPHYSICS.

"I THOUGHT OF A
LABYRINTH OF
LABYRINTHS, OF ONE
SINUOUS SPREADING
LABYRINTH THAT





FIFTH DIMENSION

VIRTUAL UNREALITY

THE WORLD WITHIN A WORLD THAT CAN PROTECT YOU FROM HACKERS.

BY ANDY GREENBERG

ILLUSTRATION BY JELLE MARTENS

EIGHT YEARS AGO, Polish hacker Joanna Rutkowska was experimenting with rootkits—tough-to-detect spyware that infects the deepest level of a computer's operating system—when she came up with a devious notion: What if, instead of putting spyware inside a victim's computer, you put the victim's computer inside the spyware?

At the time, a technology known as virtualization was becoming easier to implement on PCs, allowing anyone to create a miniature operating system, known as a virtual machine, inside their main operating system. Rutkowska manipulated virtualization into a mind-contorting weapon called a Blue Pill attack. Without them knowing, her rootkit moved the victim's entire OS into a virtual machine controlled by the hacker, allowing everything the target did to be watched. The victim's digital world would suddenly exist inside an alternate reality, and no amount of antivirus or antirootkit scanning could break the system out of that aquarium. "Your operating system swallows the Blue Pill and it awakes inside the *Matrix*," Rutkowska wrote in a blog post explaining the trick. Eventually she honed the maneuver so that not even launching another virtual machine inside the Blue Pilled system would glitch the illusion—her attack supported a dream within a dream.

But as years passed, no real-world instances of Blue Pill attacks were discovered, even after other researchers developed tests capable of detecting the technique. Rutkowska's explanation? For normal spies and cybercriminals, ordinary rootkits work just fine. "There are still so many places in a Windows kernel to hide traditional malware," she says. "I was as vulnerable as any other user. This was annoying."

So Rutkowska flipped the game, this time in favor of the defenders. Four years ago her Warsaw-based firm, Invisible Things Lab, started developing its own operating system known as Qubes. The free open source OS lets users set up a collection of virtual machines on their PC, with a simple central interface to manage each quarantined system. Careful users can keep their personal online activities isolated in one virtual machine, for instance, while they do their work in another, and their banking in a third. (Rutkowska typically runs about 15.) Open a malicious email attachment or click on an infected website and the malware can't break out of that one contaminated container.

Qubes currently works with Linux, though a Windows version is in beta testing. It requires serious geek chops to set up. But Rutkowska is working to make Qubes easier to use and hopes to offer custom versions to corporate customers. If it works as promised, even NSA-level exploits would be contained to a single compartment in Qubes' architecture, one that could be evaporated and re-created at will. Recovering from even the nastiest hacker attack, in other words, could soon be as easy as waking from a bad dream.

Joanna Rutkowska
The metahacker turned the notion of spyware—and defenses against it—inside out.

PORTRAIT BY JOE MCKENDRY

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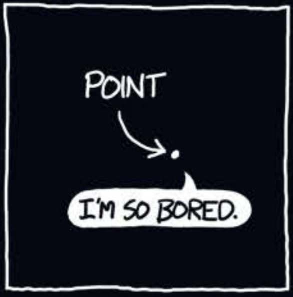
FIFTH DIMENSION

THE XKCD GUIDE TO DIMENSIONS

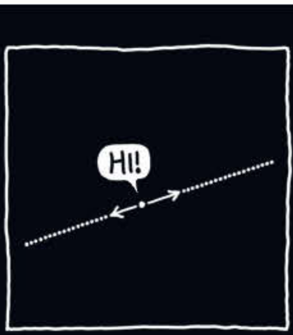
IT'S HARD TO WRAP OUR MINDS AROUND HIGHER-UP DIMENSIONS. ONE WAY TO DO IT IS TO THINK ABOUT THE DIFFERENCE BETWEEN COMICS AND MOVIES.

BY RANDALL MUNROE

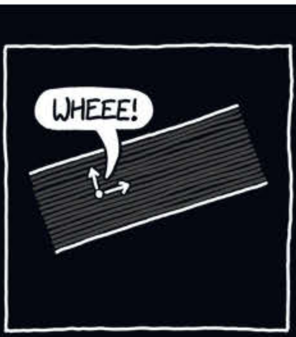
FIRST, THE BASICS



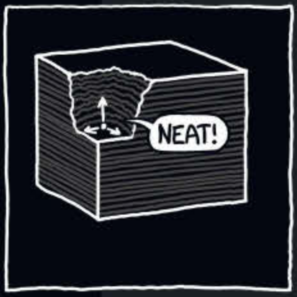
Zero-dimensional space is a single point. If you live in zero-dimensional space, you are stuck with nowhere to go and nothing to do.



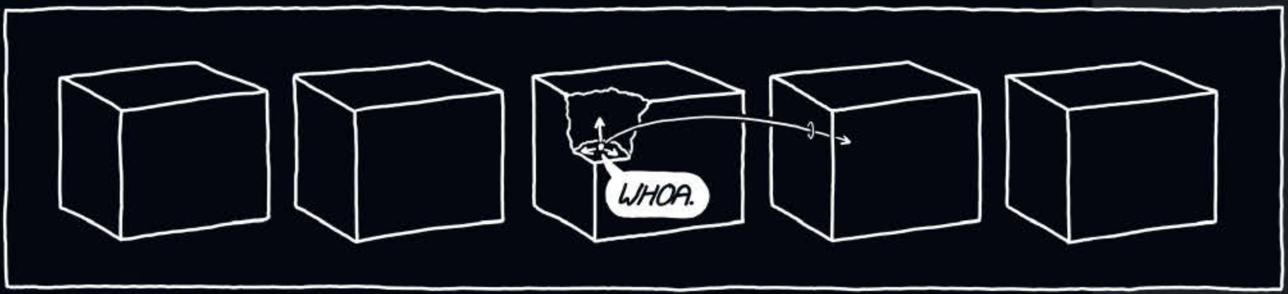
One-dimensional space is a series of neighboring points. If you move in the first dimension, you find yourself on a different point. We call this a line.



Two-dimensional space is a series of neighboring spaces. If you move in the second dimension, you find yourself on a different line. We call this a plane.

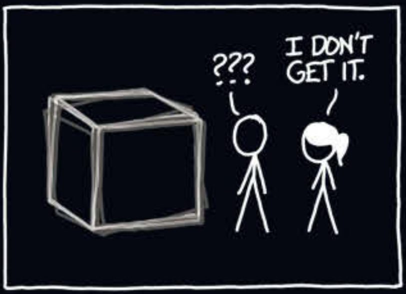


Three-dimensional space is a series of neighboring planes. If you move sideways in the third dimension, you find yourself on a different plane. We just call this "space."



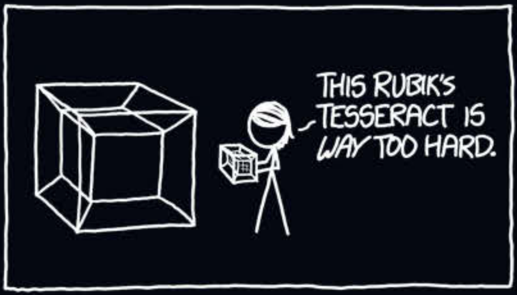
Four-dimensional space is a series of neighboring spaces. (Wait, you say, isn't the fourth dimension time? We'll get to that in a moment.) Anyway, if you move sideways in the fourth dimension, you find yourself in a different space. It's that simple. However, figuring out how to visualize it can be difficult.

Randall Munroe is the author of *What If: Serious Scientific Answers to Absurd Hypothetical Questions,* published in September.



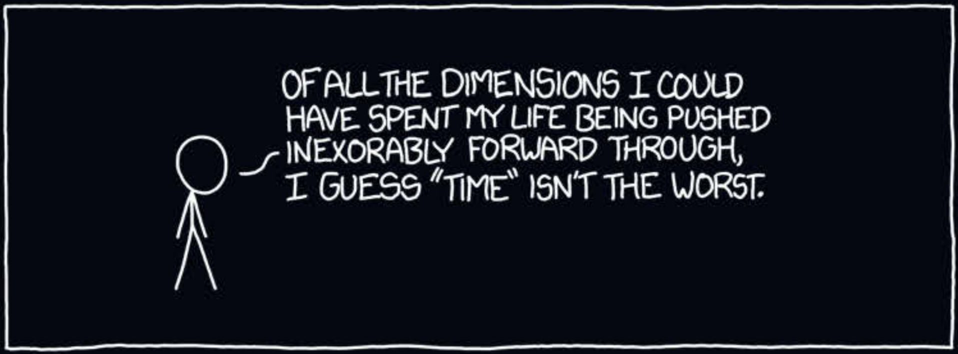
As in the first dimension, every point on a 4-D cube should be "touching" the corresponding point on its neighboring cubes. But if we try to draw it that way, with all the cubes right on top of one another, we just get a jumble.

And frankly, cubes are hard enough to draw as it is.


THIS RUBIK'S TESSERACT IS WAY TOO HARD.

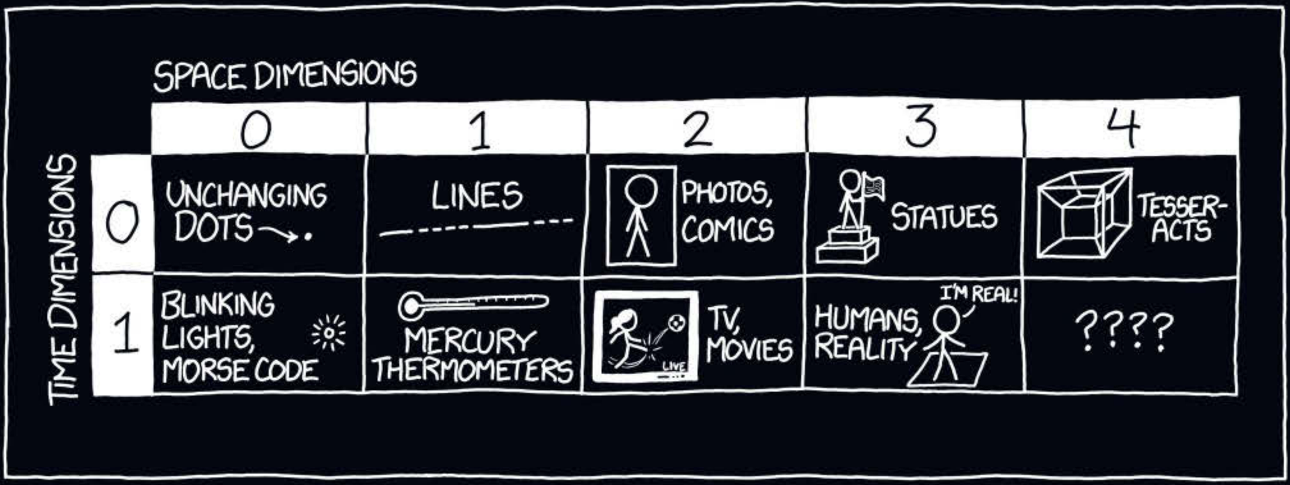
People have tried all kinds of ways of showing 4-D shapes, some more effective than others. One of the most popular ways is to show the fourth dimension receding toward the center of the object. This is a 4-D version of perspective drawing.

RIGHT, SO, TIME


OF ALL THE DIMENSIONS I COULD HAVE SPENT MY LIFE BEING PUSHED INEXORABLY FORWARD THROUGH, I GUESS "TIME" ISN'T THE WORST.

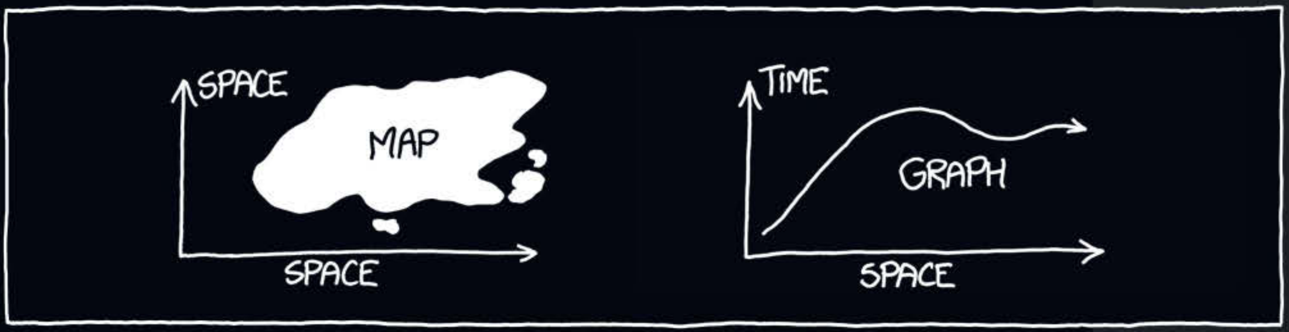
Time is always a little confusing. Time is a dimension, but for us humans, it's a little different from the space dimensions, so we don't always include it when we're making a list. The main reason time is different is obvious: You can move back and forth in all three space dimensions, but you're pushed (almost) steadily forward in the time dimension throughout your life, with no going back.

When we talk about four-dimensional stuff, we usually mean four dimensions of space—plus, optionally, one of time. So a true four-dimensional creature would exist in five dimensions altogether. We humans get only three dimensions of space, but some people include time and call us four-dimensional. This is just an ambiguity of language, and there's no getting around it. Here are some things with different numbers of dimensions.

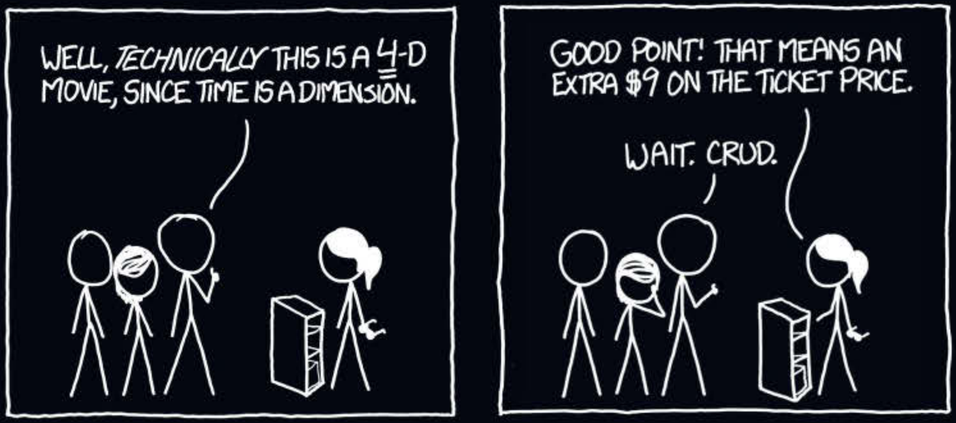


TIME DIMENSIONS \ SPACE DIMENSIONS	0	1	2	3	4
0	UNCHANGING DOTS → .	LINES	PHOTOS, COMICS	STATUES	TESSERACTS
1	BLINKING LIGHTS, MORSE CODE	MERCURY THERMOMETERS	TV, MOVIES	HUMANS, REALITY	????

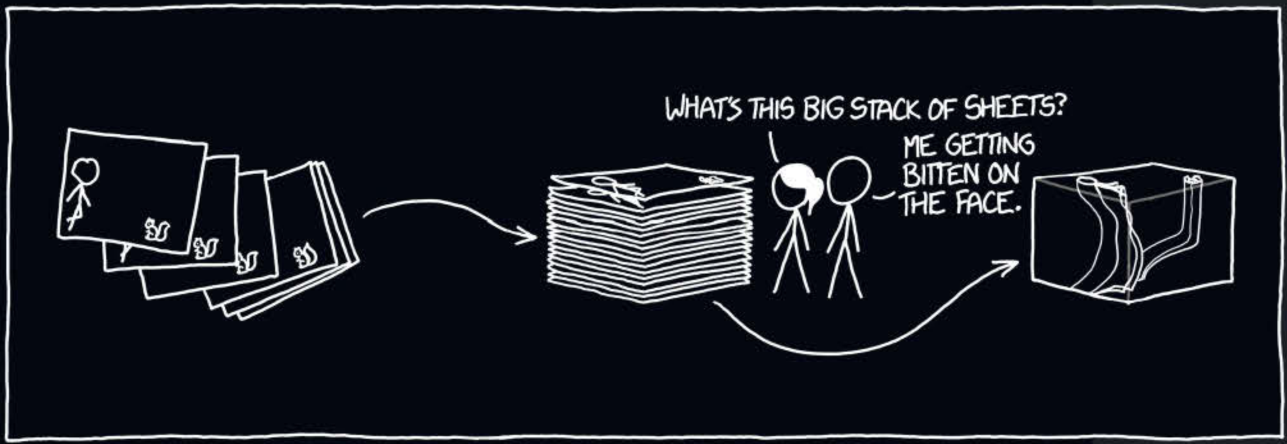
LIVE
I'M REAL!



The idea that time is a dimension is really not so strange. We often use a space dimension as a stand-in to represent a time dimension. A drawing of something has two space dimensions. If both space dimensions in the drawing represent space dimensions in real life, we call it a map or a picture. If one of them represents the time dimension, we call it a graph.

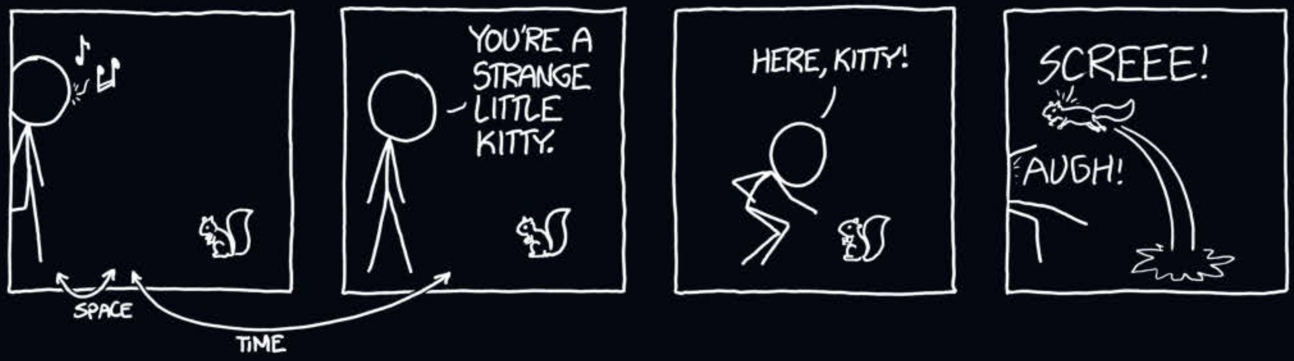

WELL, *TECHNICALLY* THIS IS A 4-D MOVIE, SINCE TIME IS A DIMENSION.
GOOD POINT! THAT MEANS AN EXTRA $9 ON THE TICKET PRICE.
WAIT. CRUD.

Movies and comics are different. Movies make use of the time dimension—changing over time—while comics are static. In this way, movies have one dimension of time, while comics have zero. Both movies and comics have two spatial dimensions, because they're both designed to be projected onto the two-dimensional retinas in our eyes. "3-D" movies aren't really three-dimensional; they're effectively 2-D images with a little bit of additional depth information.

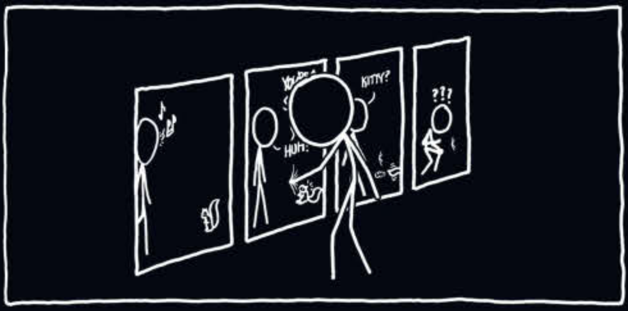

WHAT'S THIS BIG STACK OF SHEETS?
ME GETTING BITTEN ON THE FACE.

Often, we want to show pictures of things changing over time. For example, say you want to depict someone trying to pet a squirrel. In this case, you have a minimum of three dimensions you need to worry about. You need two dimensions to show the picture of the scene, and you need to show the scene changing over time, which adds a third dimension. Movies and comics solve this problem differently. Movies show changes over time by having the picture change over time. They show the passage of time using time itself. You could also use the third spatial dimension to represent time, lining up all the images to make a cube. We don't usually do this—partly because it requires a 3-D printer, but also because our two-dimensional retinas can't see the inside of the cube. If there are too many objects, they block each other and we can't see them all at once.

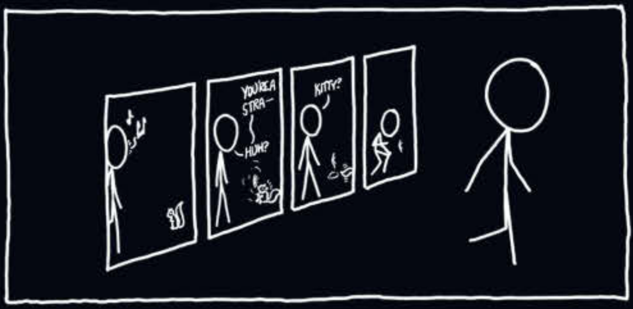
ANOTHER WAY TO REPRESENT DIMENSIONS IS TO SUPPRESS ONE OR MORE OF THEM


YOU'RE A STRANGE LITTLE KITTY.
HERE, KITTY!
SCREEE!
AUGH!
SPACE
TIME

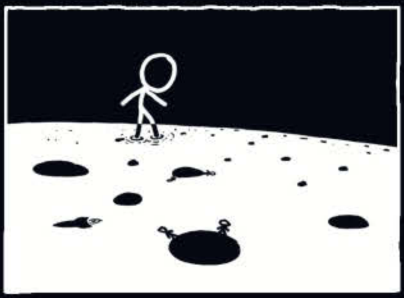
This is what comics do. They re-use one of the two space dimensions to represent time. In a comic, a small step sideways (in any direction) represents a movement in space, but a big step sideways represents a movement in time. To make room for another dimension, you have to trade in one—or part of one—you already have. In graphs, you give up one spatial dimension completely in order to represent a time dimension. In comics, by limiting the size of the panels, you give up some of the spatial dimension … but in return, you gain room to show some of time.


YOU'RE A
HUH?
KITTY?
?!?

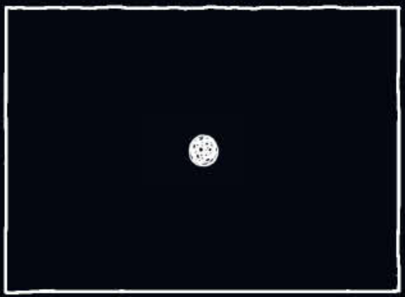
For a higher-dimensional being, our 4-D space might look to them like a comic looks to us—they'd see our reality spread out in front of them, both time and space. But unlike a comic, they wouldn't be looking at a representation of time. They would be looking at time itself. They could touch one of the "panels" and see the changes propagate outward into later panels.


YOU'RE A STRA-
HUH?
KITTY?

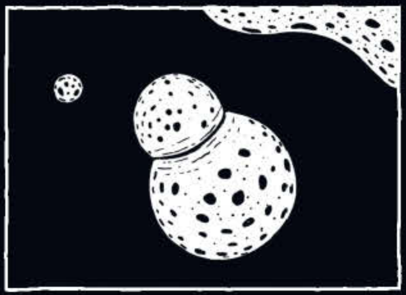
Our universe might have four dimensions. Or maybe five, as in Lisa Randall's warped geometries. Or maybe, as Leonard Susskind argues, it's best to think of space as a hologram on a 2-D surface. This article is 2-D, trapped on this flat, static sheet. It will never change. But within its limits, we can talk about depth, height, and time. It just takes the right pictures.



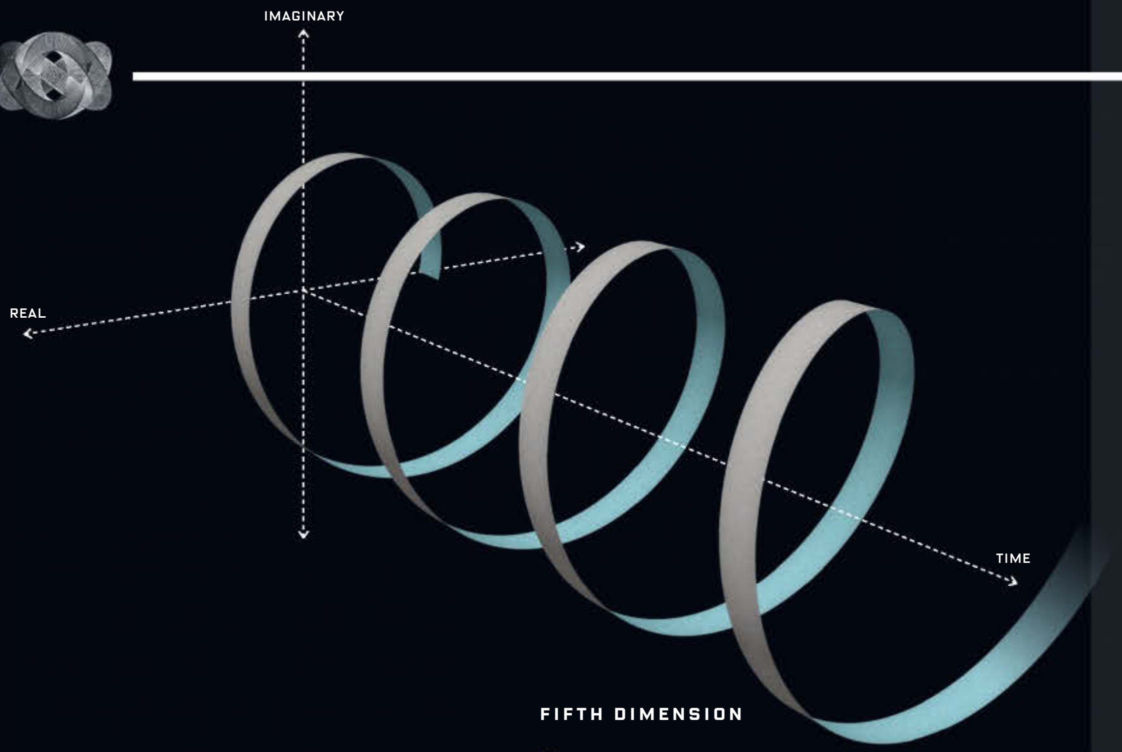
Ordinary space is too big to think about, but a higher-dimensional world is big in a whole new way. Four-dimensional space is just too big for our 3-D brains to process. To imagine it, we make room by suppressing a dimension, picturing space as a sheet.



Carl Sagan described our planet as a "lonely speck in the great enveloping cosmic dark." Perhaps the four-dimensional spacetime of our universe, like the surface of a tiny bubble or fluttering sheet, floats embedded in a far greater, deeper five-dimensional cosmic dark.



Other universes may float past ours or even collide with it. Today astronomers search the sky for scars from those collisions, looking for hints. How many dimensions are there? How big is space? How old is time? How deep is the darkness surrounding us?



FIFTH DIMENSION

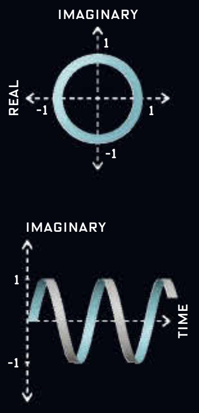
$e^{i\pi}+1=0$

EULER'S IDENTITY IS BAFFLING, SUBLIME—AND AWFULLY HANDY.

BY LEE SIMMONS

ILLUSTRATION BY ONFORMATIVE

MATH GEEKS extol its beauty, even finding in it hints of a mysterious connectedness in the universe. It's on tank tops and coffee mugs. Aliens, apparently, carve it into crop circles (in 8-bit binary code). It's appeared on *The Simpsons*. Twice. ¶ What's the deal with Euler's identity? Basically, it's an equation about numbers—specifically, those elusive constants π and *e*. Both are "transcendental" quantities; in decimal form, their digits unspool into infinity. And both are ubiquitous in scientific laws. But they seem to come from different realms: π (3.14159 ...) governs the perfect symmetry and closure of the circle; it's in planetary orbits, the endless up and down of light waves. *e* (2.71828 ...) is the foundation of exponential growth, that accelerating trajectory of escape inherent to compound interest, nuclear fission, Moore's law. It's used to model everything that grows. ¶ What Leonhard Euler showed in 1748 is that π and *e* are deeply related, but in a very weird way: They're connected in a dimension perpendicular to the world of real things, a place measured in units of *i*, the square root of –1, which doesn't actually ... exist. Mathematicians call it an imaginary number. ¶ Courage, pilgrim! Imagine a graph with real numbers on the horizontal axis and, well, imaginary ones on the vertical. Now, remember the exponential function, $f(x) = e^x$, from high school math? Ordinarily it graphs as an upward swooping curve—the very paradigm of progress. But in this "complex" space, e^{ix} traces *a circle around the origin*—an endless wheel of samsara intercepting reality at –1 and +1. Add a dimension for time and it's a helix winding into the future; viewed from the side, that helix is a sine wave. That's the alchemy of Euler's formula: It equates disruptive, exponential change (the land of *e*) and infinite repetition (π). You might think you're getting ahead in the world, but from this astral perch, you're just running laps.



In 2-D, Euler's formula describes a circle. Add a dimension for time and it becomes a Slinky (top of page). Move around to the side and the Slinky becomes a sine wave.

The coolest part is that it works in reality too. By translating one type of motion into another, Euler's equation lets engineers convert messy trig problems (sines, secants, etc.) into more tractable algebra—like a wormhole between branches of math. It's the secret sauce in Fourier transforms used to digitize music, and it tames all manner of wavy things in quantum mechanics, electronics, and signal processing; without it, computers might not exist. The takeaway? Those crop-circle aliens were trying to tell us something.

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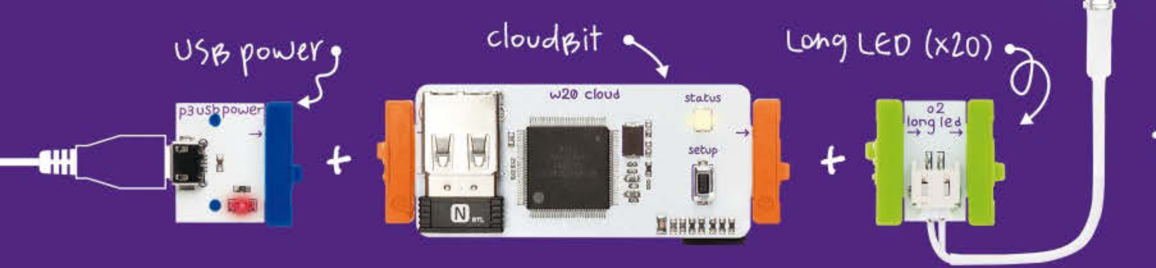

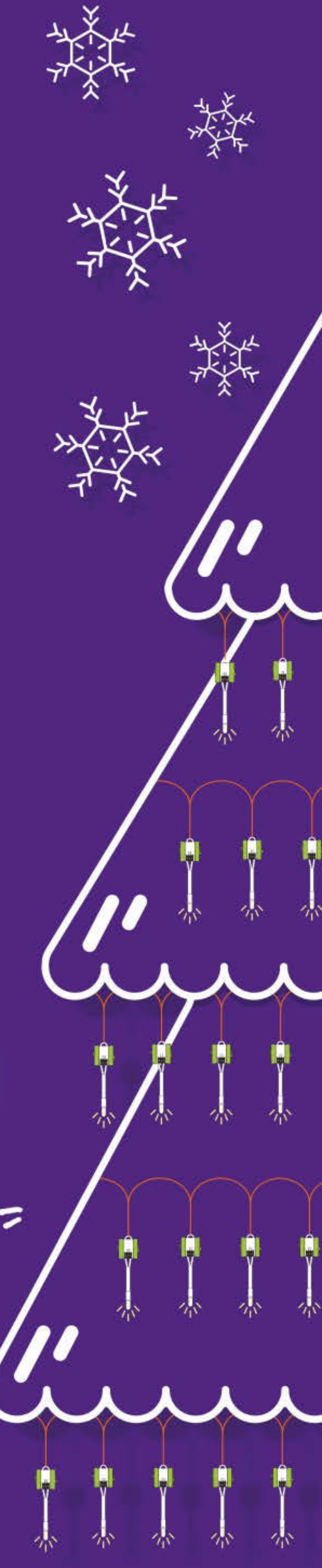

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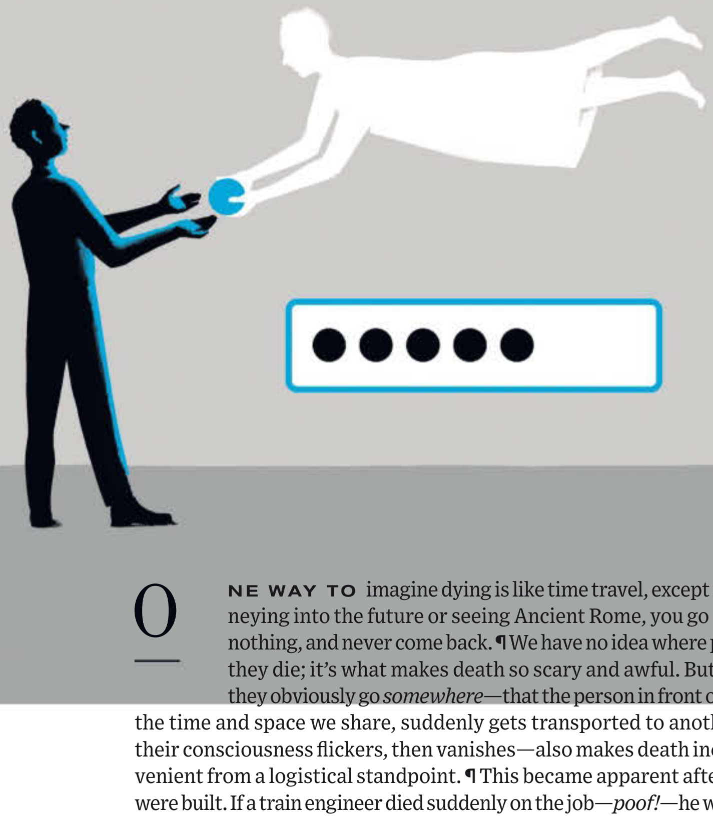
FIFTH DIMENSION

THE TALKING DEAD

COMMUNICATION FROM BEYOND THE FINAL FRONTIER.

BY JON MOOALLEM

ILLUSTRATION BY CHRISTOPH NIEMANN



ONE WAY TO imagine dying is like time travel, except instead of journeying into the future or seeing Ancient Rome, you go to eternity, see nothing, and never come back. ¶ We have no idea where people go when they die; it's what makes death so scary and awful. But the sense that they obviously go *somewhere*—that the person in front of us, situated in the time and space we share, suddenly gets transported to another realm; that their consciousness flickers, then vanishes—also makes death incredibly inconvenient from a logistical standpoint. ¶ This became apparent after the railroads were built. If a train engineer died suddenly on the job—*poof!*—he would be instantaneously swapped out for a lifeless lump of matter while the huge steel machine he'd been driving kept barreling down the tracks. To get around this problem, the railroad companies devised a "dead man's switch": a pressure-sensitive lever or pedal held down by the engineer as he drives. "If the guy suddenly plotzes," neuroscientist David Eagleman explains, "he'll release the switch and stop the train." Eagleman had this antiquated technology in the back of his mind when he sat down to write a short science fiction story called "A Brief History of Death Switches." The story begins with a familiar problem: "At the beginning of the computer era, people died with passwords in their heads." ¶ It was an administrative nightmare, with emails, photos, diaries, and financial information locked away for all eternity simply because people kept crossing into the beyond with the only set of keys. Eventually, Eagleman writes, a solution emerged: software called Death Switches that would detect a person's demise and send prewritten, postmortem emails to next of kin, sharing passwords. But it didn't take long, Eagleman goes on, for people to realize they could communicate more than passwords. They could say good-bye or get in the last word of an argument.

As it turns out, Eagleman wasn't just writing fiction. In 2006 he launched a real-life startup, Deathswitch, to provide the service. Subscribers are prompted periodically via email to make sure they're still alive. When they fail to respond, Deathswitch starts firing off their predrafted notes to loved ones. The company now has thousands of users and effectively runs itself. Among the perks of a premium Deathswitch account is the ability to schedule emails for delivery far in the future: to wish your wife a happy 50th wedding anniversary, for example, 30 years after you left her a widow.

Death is the original other dimension—a parallel universe that, for millennia, we have anxiously tried to understand. As software, Deathswitch is relatively simple, but as a tool in that millennia-long project it can feel spine-chillingly disruptive. Eagleman has jury-rigged a way for people to speak from beyond that inviolable border and—for those of us still sticking it out on this side—to feel we're being spoken to. It's another example of technology enabling things that previously would have seemed magic.

Now that so much of our lives gets converted into data that outlasts us, this kind of trans-dimensional communication may be more useful than ever. (Google has even launched its own prosaic version of Eagleman's service: the Inactive Account Manager, which helps users plan their "digital afterlife," apportioning out access to Gmail, Google Drive, etc., just like heirlooms being distributed in a will.) But Eagleman sees the value of Deathswitch as stretching beyond the utilitarian. The system is completely encrypted and anonymous—even he can't see inside the black box. Still, he likes to imagine the many sensational messages, waiting to be delivered: unexpected declarations of love, confessions of secrets or crimes, or the location of buried cash.

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THE METAPHYSICS OF *INTERSTELLAR*

A CONVERSATION WITH KIP THORNE AND CHRISTOPHER NOLAN.

DAN WINTERS

Continued from page 46

ONE OF THE problems with a story that depends on dimensions beyond space and time is that it has to be complex but not complicated. An audience has to pick up concepts that even ace astrophysicists have trouble metabolizing. Like the proverbial observer in the theory of relativity, your perspective affects what you perceive. That's what happened to Kip Thorne and Christopher Nolan. As they hashed out the science of *Interstellar*, the scientist and the storyteller looked at the same truths and—at least for a while—saw very different things. Here's what their trip down the rabbit hole felt like. —ADAM ROGERS

WIRED: Chris, where did Kip have to rein you in?

NOLAN: There was one thing. I was determined to have a character travel faster than the speed of light.

WIRED: Uh-oh.

NOLAN: I wanted to break the light barrier, as I called it. And Kip wasn't having any of that. That went on for a couple of weeks.

THORNE: I gave him a document where I laid out the reasons it couldn't work.[1] We had a couple of conversations, and he backed down.

NOLAN: We had more than a couple of conversations. What he's not telling you is, I finally managed to get my head around relativity. I don't mean a full understanding of it. I mean a glimpse of a feeling, you know? Like when you're trying to play an instrument and you happen to hit the right chord? So I said, "You know what? I agree. Nothing can travel faster than the speed of light." And he goes, "Yeah, well, in localized regions it can't," or something. And I'm like, wait a second! Every rabbit hole has another rabbit hole at the bottom of it, and another rabbit hole.

WIRED: He incepted you with relativity.

NOLAN: Oh, very much. I lost it pretty rapidly afterward. Jonah says that through working with Kip, he finally grasped relativity for a couple of weeks, and then the writers' strike happened and he had to stop writing, and it was gone. I know exactly what he means. It's like a little window opening up. That's why the relationship between storytelling and the scientific method fascinates me. It wasn't really about an intellectual understanding. It was a feeling of grasping something.

THORNE: You call it a feeling; I would call it an intuition. And this isn't just for nonscientists. Yakov Borisovich Zel'dovich, one of the really great astrophysicists of the 20th century and a codesigner of the Russian hydrogen bomb, was a close friend of mine. He could not grasp how Hawking radiation comes out of black holes, even though he had given Stephen Hawking the key idea that underlies the concept in a conversation the three of us had. For about two years, he could not make it fit with his intuition. Then, one time I was in Moscow and I went over to his flat. He threw up his hands and said, "I understand! I give up. Hawking was right." He finally understood it in an intuitive way.

WIRED: Is that different than understanding the math?

THORNE: Very different. The math was there. The math was straightforward. Well, let me take that back—those are two different things. The math was there, and the steps in the math were straightforward, but interpreting the math was not so clear. And how you use the math depends very heavily on this intuition. It's a key part of the scientist's arsenal, as it is for the storyteller's arsenal.

WIRED: Where else did you have problems with what Chris was doing?

NOLAN: Well, time dilation.

THORNE: Chris wanted a planet with time dilation unbelievably greater than I have ever seen in physics, and I just didn't think that was possible. And he said, basically, "I gotta have it." I went home, slept on it, did a calculation, and found that if you have a black hole that spins rapidly enough, and a planet that is very close to the last stable circular orbit, you could get the time dilation he wanted. It just amazed me.

NOLAN: Our meetings never ended with definite answers. They ended with questions. As a true scientist, Kip questions everything.

THORNE: Well as a true scientist I have been proved wrong so many times that I'm very humble.

NOLAN: Even if the audience can't grasp the science, my goal was to make them understand it emotionally and for it to be clear that there's a consistency and

> "I WANTED TO HAVE A CHARACTER TRAVEL FASTER THAN THE SPEED OF LIGHT. I WANTED TO BREAK THE LIGHT BARRIER. BUT KIP WAS HAVING NONE OF THAT."

[1] Measured by an observer, the energy of someone going the speed of light reaches infinity and time slows to the point where it stops altogether.

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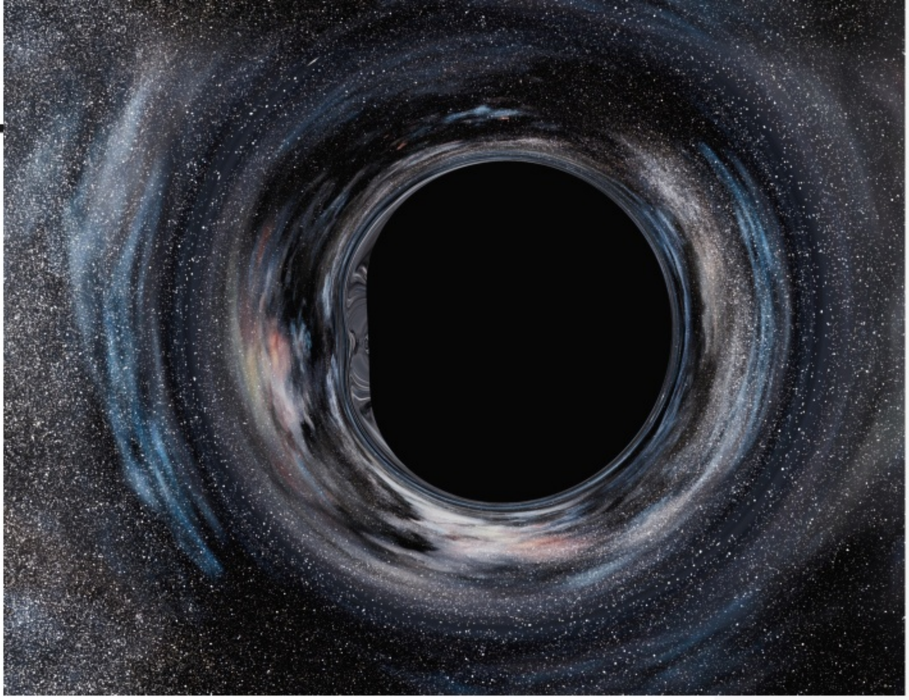

A model of how a black hole would warp light around it (minus an accretion disc), based on Thorne's equations.

COURTESY OF KIP THORNE

a reality to what we're presenting. We went back and forth about time a lot, because Kip felt that I had done certain things at the end of the film that were at odds with the rules we had talked about. Kip thought we were seeing it different ways, and the truth is we weren't. And I kind of knew we weren't. So we bounced it back and forth—

THORNE: Yeah, a whole sequence of telephone calls.

NOLAN: Well, I didn't want it to be dismissed as wild speculation. I felt very strongly that what we had done with the climax of the movie, we're basically taking—I hate to use the term, in a way—an artistic approach to the key visual element. We tried to construct a rigid geometrical idea, thinking about the work of Escher or any number of artists, and build a set that can demonstrate it. I came up with this idea of an array, a matrix representing all the information of a four-dimensional world in three dimensions, or a five-dimensional world in four, depending on where you count time. Eventually I was able to say to Kip, "I am not violating the rules."

THORNE: I was very happy with the whole tesseract scene—once he explained it to me. There is a fascinating scene earlier in the movie in which Brand (Anne Hathaway) says that to five-dimensional creatures, time is like mountains and valleys. You can go forward in time like climbing a mountain. You can go backward in time like going into a valley. It's beautifully worded. But how does that fit with Chris' rule set that says nothing can physically go backward in time? That's where I was struggling.

NOLAN: I explained that her dialogue is about analogy, it's about perspective. It all comes back to *Flatland*, I think. [See page 86.] If you're a two-dimensional being you can't see two dimensions. You can see one. If you're three-dimensional you can observe that second dimension. To me, time is like that. We can't see it. We can feel it, and we can act accordingly. But if you were a five-dimensional being looking at our world, you could observe time as a spatial dimension.

THORNE: This is where we were talking past each other. To me as a physicist there is time that flows in the fifth dimension, in the bulk, and there's time that flows in the brane[2]—our reality. They're intimately connected. But this whole business that Chris was getting at was if you live in the bulk and you're looking at how time flows in the brane, you can go forward and backward in time just fine.

NOLAN: But you can't enter the brane. And I was determined. He kept saying to me, "No, it's fine, I'm not saying it's impossible." But I didn't want to let him down. I didn't want him to think I'd broken my rule set.

THORNE: He was sure we agreed. I was sure we disagreed.

NOLAN: The geometry we constructed is an honest attempt to explain to the audience that from a higher dimension our world would look very, very different. It's an impossible task, but the attempt was tremendous fun. I wanted to be sure Kip knew we hadn't just said, "Oh, here's the crazy bit."

THORNE: Oh, I never had any doubt about that. I just had a doubt whether or not what you were doing fit with general relativity in five dimensions.

NOLAN: In a way, the tesseract[3] is an analogy. Early in the film we talk about wormholes using a sheet of paper to represent the universe, and you can fold it over. But that piece of paper is representing three dimensions. You suppress the third to make it easier to understand.

WIRED: Like using two surfaces connected by a tube to diagram a wormhole, or a mass warping a sheet to represent gravity. The two-dimensional sheets stand in for three dimensions.

NOLAN: Right, you're not moving on the surface. You're moving *in* the surface. You suppress one dimension to represent what you're talking about. As Kip and I talked about the wormhole, I finally understood that it's a four-dimensional hole in three-dimensional space. And since a three-dimensional hole in two-dimensional space would appear as a circle, a four-dimensional hole would look to us like a sphere. That's why I put it in the film. It changed everything about my ability to understand dimensionality.

WIRED: But how do you get something like that across to an audience?

NOLAN: I know how to do that because of the way photographic perspective works, which is essentially two-dimensional, and the way eyes work, which is also two-dimensional. Because of diminishing perspective, because things look smaller when they're farther away, it's actually pretty damn simple to go, "OK, we jump into this sphere, and then there's a smaller sphere, and then it grows and we jump into that one." The idea that the spheres at either end of a wormhole would be the same size? Photographically that's no problem. We filmmakers deal with that kind of thing all the time.

WIRED: Fundamentally, film always flattens a three-dimensional world onto a surface. It's not just metaphor.

NOLAN: That's why I object to the term "3-D" for stereoscopic imaging, because movies are already three-dimensional. A photograph represents three dimensions in two. And then a strip of film adds time. That's how you take time and you represent it physically: *a reel of film running through a projector.*

Continued on page 46

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[2] A brane is, technically, an object in a spacetime. It's a mathematical concept for thinking about multiple dimensions.

[3] The four-dimensional analog of a cube.

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1. Location of known office of Publication is 4 Times Square, New York, NY 10036.
2. Location of the Headquarters or General Business Offices of the Publisher is 4 Times Square, New York, NY 10036.
3. The names and addresses of the Publisher, Editor and Managing Editor are: Publisher, Kim Kelleher, 4 Times Square, New York, NY 10036. Editor, Scott Dadich, 520 Third Street, 3rd Floor San Francisco, CA 94107. Managing Editor, Jacob Young, 520 Third Street, 3rd Floor, San Francisco, CA 94107.
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ALTERNATE REALITIES THAT HELPED GET THIS ISSUE OUT:

Playing a soldier in *Gears of War 2*; a lovely beach weekend; *American Sniper*, by Chris Kyle; Childe Fergus' postulation that maybe we're all a little color-blind, because how can we ever truly see what someone else sees?; Mahler's *Kindertotenlieder*; seeing stars after so many stripes at the Gadget Lab photo shoot; NyQuil + season one of *Outlander*; that time Eddie Redmayne came to the office and told us about *Jupiter Ascending*; proving to a 6-year-old that *Ratchet & Clank* is better than *Skylanders*; eye-hiking Google Street View Treks from my computer; wondering momentarily if maybe we're all brainwashed except the North Koreans; "New York City" at The Studios at Paramount; daylight saving time.

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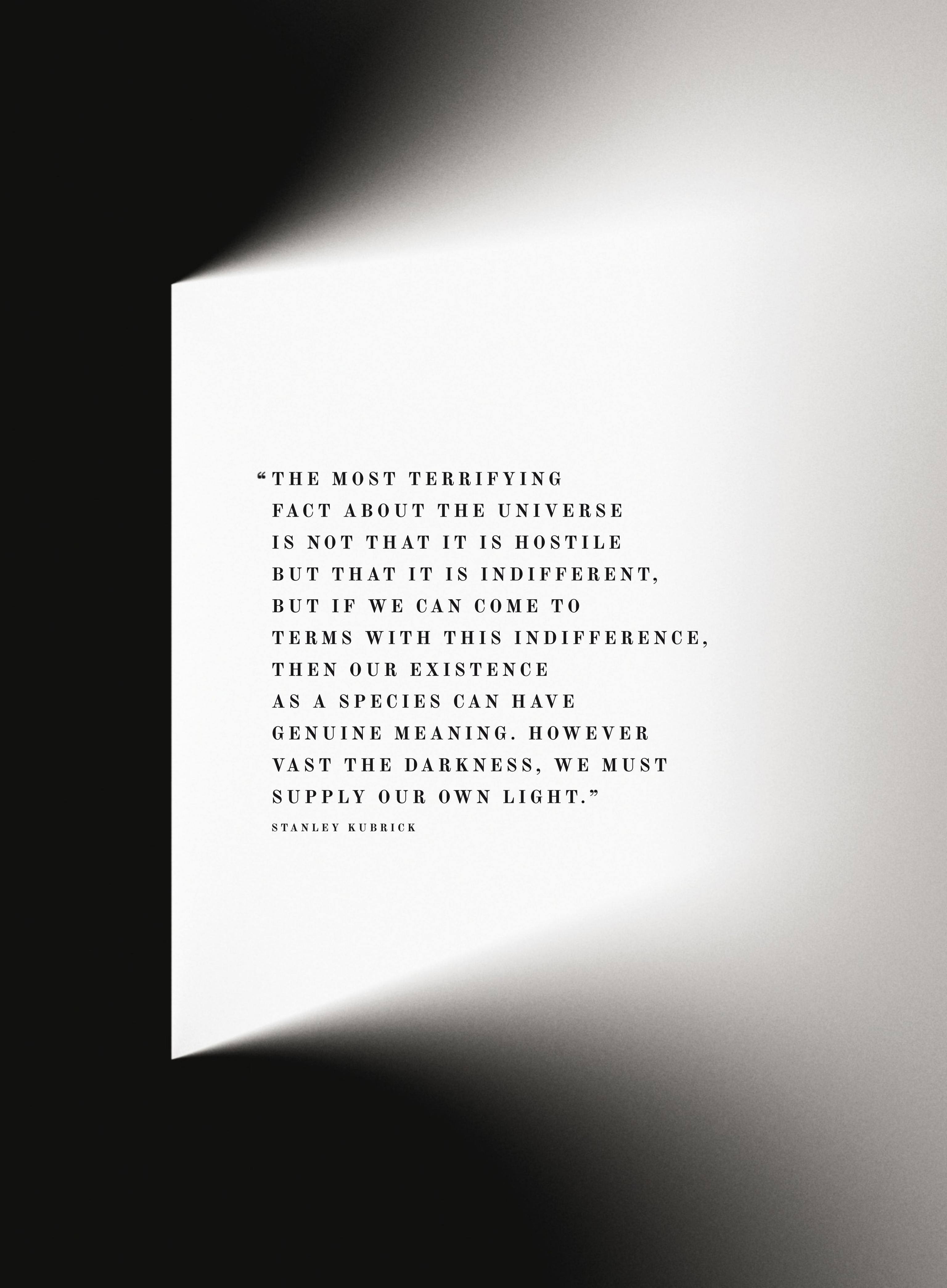

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